Exponent

Feasibility Study Work Plan: Avtex Fibers Superfund Site, Operable Unit 7

Prepared for

FMC Corporation
Philadelphia, Pennsylvania

AR302105

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Acronyms and Abbreviations

amsl	above mean sea level
AOC	Administrative Order on Consent
ARARs	Applicable or Relevant and Appropriate Requirements
AST	aboveground storage tank
ASTM	American Society for Testing and Materials
Avtex	Avtex Fibers, Inc.
BEHP	bis(2-ethylhexyl)phthalate
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
COD	chemical oxygen demand
DAPL	dense aqueous-phase liquid
DNAPL	dense nonaqueous-phase liquid
DQO	data quality objective
EE/CA	*engineering evaluation/cost analysis*
EPA	U.S. Environmental Protection Agency
ERH	electrical resistance heating
ERM	Environmental Resources Management, Inc.
FMC	FMC Corporation
FS	feasibility study
FSAP	Field Sampling and Analysis Plan
FTAP	Field Treatability and Analysis Plan
FTIR	Fourier transform infrared spectroscopy
HHRA	human health risk assessment
LTAP	Laboratory Treatability and Analysis Plan
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
OU	*Operable Unit* (e.g., OU-7)
PCBs	polychlorinated biphenyls
PID	Photoionization detector
QAPP	Quality Assurance Project Plan
RAO	remedial action objective
RBC	risk-based concentration
redox	reduction/oxidation
RfD	reference dose
RI	remedial investigation
ROD	Record of Decision
SMCL	secondary maximum contaminant level
SVOC	semivolatile organic compound
SWCB	State Water Control Board (Virginia)

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TBC	to be considered
TAL	target analyte list
TCL	target compound list
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
UST	underground storage tank
VOC	volatile organic compound
WWTP	wastewater treatment plant
XRD	x-ray diffraction

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1. Introduction

This document is a Feasibility Study (FS) Work Plan for Operable Unit 7 (OU-7) of the Avtex Fibers Superfund Site (Avtex site). Operable Unit 7 encompasses viscose basins 9, 10, and 11, groundwater, and surface water, as defined in the Consent Decree between U.S. EPA Region III (EPA) and FMC Corporation (FMC; U.S. EPA 1999a). Based on the findings of the FS conducted under this work plan, the EPA will issue a Record of Decision (ROD) for OU-7, which will select the remedial action to be implemented.

The objective of this work plan is to develop appropriate remedial action objectives (RAOs) for OU-7, and to describe the work to be conducted to identify and screen potential remedial technologies that will accomplish these RAOs. Section 2 of this Work Plan presents an overview of the site history and physical setting. Section 3 reviews the findings of the 1988 Remedial Investigation (RI; Geraghty and Miller 1988) and the comprehensive RI investigation conducted in 1993–1994 (ERM 1994), and develops a conceptual site model describing the origin, evolution, and fate of contaminants at the site. This conceptual site model allows for identification of data requirements for the supplemental site characterization efforts that are necessary to support the OU-7 FS. The data collected during the RI investigations are substantively complete and are compiled in the site database developed and maintained for FMC by Environmental Systems & Technology (ES&T), of Blacksburg, Virginia. The supplemental characterization efforts specified in this work plan fill site characterization data gaps, and focus primarily on collecting the data necessary to evaluate remedial technologies.

Section 4 of this work plan presents a risk-based screening of chemicals in groundwater, with the objective of focusing the supplemental characterization on the most important chemicals in groundwater. This risk-based screening does not preclude the need for a human health risk assessment (HHRA) for groundwater, and one will be prepared and submitted to EPA once the supplemental groundwater characterization has been conducted.

Section 5 identifies Applicable or Relevant and Appropriate Requirements (ARARs) and presents preliminary RAOs for the FS. Section 6 identifies the elements of work required to complete the FS, including the supplemental site characterization needs. This scope of work does not necessarily include all of the elements necessary to complete the FS, because additional needs (e.g., field treatability studies) may be identified during preparation of the FS.

The Field Sampling and Analysis Plan (FSAP), which provides a detailed description of the field sampling and analysis activities required to implement this work plan, is provided under separate cover. Note that the FSAP also covers the sampling of 16 groundwater wells that have been identified as the groundwater monitoring network for OU-10 (viscose basins 1–8 and new landfill) at the site. Field activities and related

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analytical work will be conducted in accordance with the site-wide Quality Assurance Project Plan (QAPP; ERM and ECC 1999) and the site-wide Health and Safety Plan (HASP; FMC 1999). However, Appendix A includes an addendum to the site-wide HASP, under which the supplemental site investigation work will be conducted.

2. Background

2.1 Site Description

The Avtex site is a former rayon manufacturing facility located at 1169 Kendrick Lane, in Front Royal, Virginia (Figure 2-1). The site occupies approximately 440 acres of land, and is bounded to the north by the General Chemical property, to the south and east by the Randolph Macon Academy and residential properties, and to the west by the South Fork of the Shenandoah River (Figure 2-2). The Shenandoah National Park is located upriver, approximately one mile south of the site. A Norfolk Southern Railway Company line approximately bisects the site, separating the former plant area to the east from the land disposal impoundments and wastewater treatment plant to the west. The former plant-area buildings occupied approximately 60 of the nearly 200 acres of the site east of the railroad tracks. There are a total of 25 land disposal impoundments west of the railroad tracks, which cover a majority of the acreage in this portion of the site.

The American Viscose Corporation began construction of the manufacturing facility in 1937 and began rayon production in 1940. Rayon was manufactured continuously at the site until its closure in 1989. Polyester was produced for a brief period (1970–1977), and polypropylene was manufactured at the site from 1985 to 1989. The site was added to the National Priorities List (NPL) in 1986. During 1942–1945, the United States Department of Commerce War Production Board controlled plant operations. In 1963, the site was sold to FMC, which operated the facility until 1976, when it was sold to Avtex Fibers, Inc. (Avtex).

2.2 Site Environmental and Regulatory History

This section provides an overview of the environmental and regulatory history of the Avtex site. Information from prior to 1993 was obtained from the EPA's Remedial Investigation/Feasibility Study (RI/FS) work plan (Halliburton/Gannett Fleming 1993). Sources of more recent historical information are referenced as appropriate.

Environmental concerns at the Avtex site initially focused on the effects of the discharge of plant wastewater to the South Fork of the Shenandoah River (see the summary of site history in Table 2-1). In response to a directive issued by the Virginia State Water Control Board (SWCB) in 1948, American Viscose constructed a wastewater treatment plant (WWTP) to treat acid, alkaline, and sulfide waste streams generated as by-products of rayon production. In 1977, a National Pollutant Discharge Elimination System (NPDES) permit was issued to Avtex specifying effluent limitations and monitoring requirements on discharges to the river. In response, Avtex and the SWCB entered into a Consent Order specifying the installation of acid and alkaline neutralization facilities. Despite these provisions, the NPDES permit limitations were exceeded frequently until the site was closed in 1989.

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Additional environmental concerns surfaced in 1982, when elevated concentrations of carbon disulfide were found in residential groundwater wells in Rivermont Acres—a subdivision on the west bank of the Shenandoah River across from the site (Figure 2-1). In response to a request from the SWCB, Avtex performed a groundwater investigation. Based on this investigation, Avtex implemented interim groundwater remedial measures in 1983–84, including purchasing 23 undeveloped lots in Rivermont Acres and Fiddler's Green subdivisions, counter-pumping groundwater, and draining water from viscose basins 9, 10, and 11, which were identified as the primary source of carbon disulfide to groundwater. In 1986, Avtex and EPA entered into an Administrative Consent Order specifying that an RI/FS be performed to further investigate groundwater contamination resulting from viscose waste disposal at the site. The Consent Order was amended in 1988 to include FMC as a respondent. The RI/FS, conducted by Geraghty and Miller and released in August 1988, confirmed that viscose basins 9, 10, and 11 were the primary source of the groundwater contamination. Based on the results of the RI/FS, a ROD for the groundwater operable unit (OU-1) was issued in September 1988 requiring dewatering of the three basins and pumping and treatment of contaminated groundwater.

In June 1989, the EPA issued an Administrative Order to Avtex and FMC to undertake the groundwater remedial activities prescribed in the ROD for OU-1. In November of that year, as part of ongoing enforcement actions, the State of Virginia revoked Avtex's NPDES permit for the WWTP in November 1989. As a result, Avtex shut down the WWTP, abandoned the site, and notified the EPA that the company could no longer comply with the June 1989 Administrative Order. In November 1989, the EPA began emergency response and time-critical removal actions at the site under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). These measures included removal of bulk chemicals, drums, and containers, and demolition of site buildings and structures.

In December 1989, the EPA requested that FMC conduct a new RI to establish a final groundwater remedy for the site. In February 1993, Halliburton NUS Environmental Corporation and Gannett Fleming, Inc., under the direction of the EPA, completed the Work Plan for the RI/FS (Halliburton/Gannett Fleming 1993). In April 1993, EPA and FMC entered into an Administrative Order on Consent (AOC) to perform an RI/FS (EPA 2000a). RI-related field activities were initiated in 1993 by FMC's consultant, Environmental Resources Management, Inc. (ERM). A report summarizing the findings of FMC's RI activities was issued by ERM in 1994 (ERM 1994).

In March 1999, the EPA completed the final ecological risk assessment for the site and the adjacent reach of the South Fork of the Shenandoah River (U.S. EPA 1999b). The final engineering evaluation/cost analysis (EE/CA) for closure of the sulfate basins, WWTP basins, and fly ash basins and pile was completed in May 1999 (ERM 1999a), and a draft baseline human health risk assessment for the onsite soils, sulfate basins, WWTP basins, viscose basins, and the fly ash basins and pile was completed in December 1999 (Gradient 1999).

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2.3 Overview of Rayon Manufacture at the Avtex Site—the Viscose Process

Rayon fiber was manufactured continuously by the viscose process at the Avtex site from 1940 to 1989. A schematic of the viscose process used for the production of rayon at the Avtex facility is presented in Figure 2-3. A more complete description of the viscose preparation process and chemistry can be found in Appendix A. In this process, rayon-grade pulp (cellulose) sheets were steeped in a caustic soda solution to initiate the conversion of the cellulose to a liquid form. Excess caustic soda was then squeezed from the sheets, and the sheets were shredded to form an intermediate product termed "crumb." After aging, the crumb was reacted with carbon disulfide to form cellulose xanthate, which in turn, was dissolved in caustic soda to produce a thick, orange solution termed "viscose." Phenol and ethylene diamine (urea) were added to the viscose solution on a batch-by-batch basis. These compounds acted as surfactants and enhanced the spinning process (Halliburton/Gannett Fleming 1993). The viscose solution was then extruded into a sulfuric acid bath where the cellulose was regenerated as the carbon disulfide was released from the cellulose xanthate. The regenerated cellulose was then spun to form rayon fiber. Zinc and/or magnesium sulfate was added to the acid bath to retard the regeneration process, which increased the strength of the rayon fiber (Hermans 1949).

2.4 Site Facilities

For discussion purposes, the site can be divided into two location categories separated by the railroad line that runs north–south through the site. The railroad line separates the plant area to the east from the waste disposal area to the west (Figure 2-2). The plant area includes the main plant building and other facilities that were used at the site during the manufacturing process. The waste disposal area includes 25 land impoundments that were used for the disposal of plant process wastes. The site WWTP and associated facilities have also been included in the waste-area category.

2.4.1 Plant Area

The plant area includes the main building and several storage tanks, buildings, and other facilities adjacent to the main building (Figure 2-4). Construction of the main plant building that housed the rayon manufacturing process began in 1937 and was completed in 1940. Other plant-area facilities included the acid reclaim and zinc recovery facilities; a lead casting shop; a water softening facility; wood-, machine-, and pipe-shops; a coal storage area; and a power plant. In addition, the plant area had several facilities for storage of raw materials, chemicals, and intermediate and final products, including numerous aboveground storage tanks (ASTs) and underground storage tanks (USTs). Table 2-2 provides a description of some of the major plant-area facilities identified at the Avtex site as part of the RI conducted by Geraghty and Miller.

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Several potentially hazardous chemicals---such as carbon disulfide, sodium hydroxide, ethylene diamine, phenol, sulfuric acid, zinc salts, sodium sulfate, sodium hypochlorite, solvents, and fuels---were stored and handled at the site as part of the rayon manufacturing process. In addition, many intermediate products---such as crumb, cellulose xanthate, and viscose---were produced continually and stored at the site. Both the chemicals and intermediate products were present within the main plant buildings and in many of the adjacent plant-area facilities. As a result, certain plant areas represented a potential historical source of site chemicals to surrounding soils and groundwater. In 1990, the EPA identified 50 potential spill areas in the main plant buildings and adjacent areas (Halliburton/Gannett Fleming 1993). Furthermore, the site is underlain by an extensive sewer system, much of which conveyed site waste materials. The sewer system was originally constructed in 1937–1940, and currently consists of terra cotta, vitrified clay, cast iron, and concrete lines of diameters ranging from 4 to 60 inches (Halliburton/Gannett Fleming 1993). The majority of the system is constructed of terra cotta. A 1986 preliminary assessment/site inspection conducted for the EPA by the NUS corporation concluded that the sewer system is in a state of disrepair ---suggesting that during its operation, exfiltration from the system was likely a source of chemicals to surrounding soils and groundwater (as cited in Halliburton/Gannett Fleming 1993).

The majority of the hazardous substances were removed by the EPA from the plant area following plant shutdown in 1989 during the emergency response activities, and many of the plant-area buildings have been (or will be) dismantled and/or demolished during the site closure process. As part of this process, impacted soils surrounding site facilities that are identified as potential sources of site chemicals to groundwater will be remediated. As a result, sources of site chemicals from the plant area will be minimized in the near future (2--3 years).

2.4.2 Waste Disposal Areas

Although polyester and polypropylene were manufactured for brief periods at the site, rayon manufacture was the process that was primarily responsible for the site waste streams. Three primary waste streams were produced as a result of rayon manufacture:

- Liquid waste streams (including spent acid from the rayon spinning baths, and alkaline and sulfide liquid waste streams)
- Off-specification (waste) viscose
- Fly ash and boiler room solids.

These wastes were disposed of in 22 separate surface disposal impoundments located west of the Norfolk & Western Railroad easement (Figure 2-5). These impoundments include 11 viscose basins, 5 sulfate basins, 4 fly ash basins, a fly ash stockpile, and a landfill. The site WWTP is also located west of the railroad line and has been included as part of the waste disposal area for discussion purposes. The WWTP includes an additional three polishing basins and an emergency lagoon; the latter contains waste

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sludge material similar to that disposed of in the sulfate basins. A summary of the waste-area facilities can be found in Table 2-3.

2.4.3 Wastewater Treatment Plant

Waste streams produced during rayon manufacturing at the site were discharged directly to the Shenandoah River prior to 1948, when a WWTP was constructed to treat the primary acid waste stream, and the secondary sulfide and alkaline waste streams, in an attempt to reduce acid and metals loading to the river. The WWTP included a neutralization basin, two clarifiers, three polishing basins, and an emergency lagoon. The three plant waste streams were mixed, and the excess acid was neutralized by adding lime in the neutralization basin. The neutralization process produced a zinc-rich hydroxide sludge that was collected in the clarifiers. Overflow from the clarifiers passed to the polishing basins, where additional solids were collected. Underflows from the clarifiers were pumped to an extensive network of unlined basins---termed sulfate basins (see below)---where the hydroxide sludge was ultimately disposed.

The WWTP includes a conventional activated sludge plant. The activated sludge plant followed the polishing basins and provided secondary treatment to reduce organics loading to the river. The activated sludge plant includes two aeration chambers and two additional clarifiers. Waste underflow from the clarifiers was routed to a sludge thickener and digester. Digested sludge was then pumped to the sulfate basins for disposal.

The site's wastewater and stormwater were originally discharged to the river through four outfalls (Figure 2-5). Outfall 004 is still used for discharge of treated water from the WWTP. Outfalls 001 and 002 received stormwater drained from the fly ash basins and stockpile. Outfall 003 primarily received cooling water from various plant operations. Outfalls 001–003 are no longer in service, because plant operations have ceased and stormwater is now discharged from Outfall 004 (Halliburton/Gannett Fleming 1993).

Although industrial waste streams are no longer generated at the site, FMC operates the WWTP under a 1990 Administrative Order from the EPA to treat site stormwater and other waters generated by site cleanup operations, and to maintain water freeboards on the sulfate basins and the WWTP polishing basins and emergency lagoon (hereafter referred to as the WWTP basins). The WWTP will remain in operation until a final remedial alternative is developed for the sulfate basins and the WWTP basins (Halliburton/Gannett Fleming 1993). The WWTP basins are estimated to contain 12,000 and 16,500 cubic yards of zinc-rich hydroxide sludge, respectively (ERM 1994).

2.4.4 Sulfate Basins

As discussed above, the sulfate basins served as the final repository for hydroxide sludge generated by the WWTP. These sludges were pumped as slurries to the sulfate basins (identified as sulfate basins 01 through 04, 04E, and 05) located along the eastern bank of

the Shenandoah River (Figure 2-5). The sulfate basins are unlined, bermed impoundments that cover a total area of 85 acres. The basins are estimated to contain a total of 936,000 cubic yards of sludge that consists of approximately 20 percent (dry weight) zinc in the form of zinc hydroxide. Portions of the zinc-rich hydroxide sludge in the basins were mined by Avtex in the early 1980s, and the zinc was recovered in the plant area's zinc recovery facility for reuse in the plant process. A seventh sulfate basin was formerly present at the location of fly ash basin 06. However, 60–70 percent of the hydroxide sludge from the basin was removed in the early 1980s, and the basin was re-used for fly ash disposal. An estimated 80 percent of the sludge from sulfate basin 05 was also removed in 1980. The sulfate basins also received relatively small amounts of organic-rich sludge produced from the WWTP's anaerobic digester after 1990, and some untreated process water at times when the WWTP was hydraulically or organically overloaded (Geraghty and Miller 1988).

2.4.5 Viscose Basins

Off-specification, or waste, viscose was a major by-product of rayon production. Waste viscose is a highly alkaline, carbon disulfide–rich, cellulosic material. This material was disposed of in 11 unlined surface impoundments—termed viscose basins—that operated at the site at various times since 1940 (Figure 2-5). Table 2-4 summarizes the land disposal history of viscose waste at the site, a practice that was discontinued in 1983 when waste viscose was directed to the WWTP. Prior to 1963, waste viscose was hauled in Dempsey dumpsters (Halliburton/Gannett Fleming 1993) and end-dumped into basins 1–8. Waste viscose that was placed in viscose basins 9–11 was either hauled and end-dumped, or slurried and pumped through a 4-in. line (Plauger 1999, pers. comm.).

The viscose basins are estimated to contain a total volume of 535,000 cubic yards of waste viscose. Based on the site topography and logs of boreholes completed through the viscose basins, it is apparent that basins 9, 10, and 11 were excavated and bermed on the sides. As a result, these basins have little to no native soil between the waste viscose and underlying bedrock. Bedrock reportedly was removed from the bottom of basin 9 during its construction, to increase its capacity (Geraghty and Miller 1988). However, logs of boreholes within this basin do not show evidence to support this contention. Basins 1–8 may also have been excavated, as boreholes in several locations indicated little to no native soil beneath the waste viscose (See Section 3.1.1.4). Basins 4–6 historically served as a landfill for plant solid wastes, and as a result, these basins extend 5–10 ft above the natural topography. Wastes such as WWTP lime grit, air-dried sanitary sludge, off-specification crumb, used filter media, unprocessed fibers, and construction and demolition debris were deposited atop the previously deposited waste viscose in these basins (VB 4–6). This disposal area did not have a synthetic liner system or a formal leachate collection system, although seepage from the landfill was collected in trenches east and west of the landfill. The landfill was closed in 1983, when it was dewatered, graded, and capped with a soil cover, and hydroseeded. Viscose basins 1 through 8 all have a soil cover, and are vegetated to varying degrees. Basins 9, 10, and 11 are uncovered, and the exposed surface of the waste viscose has dried into a flaky crust.

Interim remedial measures were instituted to minimize further offsite migration and to reduce chemical loading from the basins. A groundwater counterpumping system was operated from March 1984 to July 1984, and from November 1984 to January 1986. During the first period of operation, the pumps became clogged with a precipitate (probably silica), and had to be refurbished (Geraghty and Miller 1988). In addition, well plugging resulted in decreased pumping rates after a year of operation. Despite the problems with precipitation in the wells, 28 million gallons of water were pumped from the system (Geraghty and Miller 1988). The 1987 RI investigation found that viscose basins 9, 10, and 11 were the source of carbon disulfide detected in the Rivermont Acres wells. Pits were excavated in viscose basins 9 and 11, and the water in the bottom of the pits was sumped and delivered to the WWTP for treatment. The viscose basin 10 berm is breached at the northwest corner, and leachate from this basin flows into sulfate basin 1, from which it is delivered to the WWTP for treatment. Sumping of the basins is still active, and it is estimated that 1.5 million gallons of leachate from the basins is treated by the WWTP each year.

2.4.6 Fly Ash Basins and Stockpile

Fly ash from the coal-fired boilers and particulate from the boiler-house dust collectors and ash hoppers were slurried in water and pumped to a series of four impoundments (fly ash basins) located west of the railroad (Figure 2-5). Fly ash particulates settled from the water column as the slurry passed through the basin. When the basin was full, it was drained and the solids were excavated and deposited on the fly ash stockpile. The stockpile was periodically covered with soil to stabilize the pile and prevent wind dispersion of the fly ash material. Fly ash basin 06 was originally a sulfate basin, but in the 1980s, it was dredged of 60–70 percent of the hydroxide sludge and converted to a fly ash basin.

2.4.7 New Landfill

As discussed above, the tops of viscose basins 4–6 were historically used as a solid waste landfill for the site. This landfill was closed in 1983, and solid wastes were directed to a new landfill constructed immediately east of viscose basins 7 and 8 (Figure 2-5). The new landfill has multiple cells, liners, and leachate collection systems tied directly to the WWTP (Halliburton/Gannett Fleming 1993). Wastes deposited in the new landfill include solidified viscose, unusable rayon fiber, lime grit, and construction debris.

2.5 Physical Setting

2.5.1 Climate

Precipitation and temperature records for the Front Royal area are available from the National Climatic Data Center for 1931–1960, and 1996 to the present. Climatic records from 1931–1960 indicate that the average annual precipitation was 38.5 inches, and the

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average daily annual temperature ranged from 34.9 °F in January to 76.1 °F in July (Table 2-5).

Rainfall data have been collected at the Avtex site since 1990, with a complete record from 1992 to the present. Based on these data, the site received an average of 42 in./year of precipitation during 1992–1998 (Table 2-6), slightly higher than the long-term (1931–1960) average. Average monthly precipitation ranges from 2.41 to 4.58 inches and is generally higher in the summer months and lower in the winter.

2.5.2 Hydrogeology

The regional and local hydrogeologic features that relate to movement of groundwater and subsurface migration of chemicals at the Avtex site are described below.

2.5.2.1 Regional Geology

Front Royal is located in a transitional area between the Valley and Ridge and Blue Ridge physiographic provinces. The Valley and Ridge province is characterized by gently rolling, linear to arcuate hills and broad valleys, whereas the Blue Ridge province contains mountainous terrain with V-shaped valleys and steep ridges. The bedrock in the Front Royal area ranges in age from Precambrian to Ordovician (Rader and Biggs 1975). The bedrock was exposed to compressive stresses, which created nearly parallel folds (anticlines and synclines), with fold axes that trend northeast/southwest (Rader and Biggs 1975). A substantial unconformity (i.e., a surface that represents an interval in time where deposition stopped, erosion removed some of the bedrock, leaving a gap in the geologic record, and then deposition resumed) is present between the bedrock and the overlying Quaternary-age surficial deposits, composed primarily of colluvium (weathered material deposited by gravity) and alluvium (weathered material deposited by a river). The surface geology in the Front Royal area is shown in Figure 2-6.

2.5.2.2 Site Hydrogeology

Hydrostratigraphic Units — Two naturally occurring geologic units are important in the site hydrogeology: the overburden and the bedrock. Groundwater occurs in both units, although only water from the bedrock is used in the adjacent rural areas for domestic water supply. The overburden, which is mapped regionally as alluvium and colluvium associated with the Shenandoah River, is composed primarily of clay and silt. Based on seismic refraction data, the overburden ranges from 3 to 50 ft thick (ERM 1993), and may be laterally discontinuous (i.e., 0 ft thick) in some areas (Geraghty and Miller 1988). The clay/silt overburden is present beneath most of the viscose and sulfate basins, with the exception of viscose basins 5 and 11, which borehole data indicate were at least partially excavated to bedrock (Section 3.1). Due to the fine-grained texture of the overburden materials, the overburden has a low vertical permeability (see Section 2.5.2.4). Geraghty and Miller (1988) concluded that the low-permeability overburden

may somewhat inhibit vertical migration of chemicals from the viscose and sulfate basins.

The bedrock underlying the overburden beneath the site is the Ordovician-age Martinsburg Formation. Its thickness is reported as 3,000 ft (Rader and Biggs 1975); thus, it is the only bedrock unit of hydrogeological importance beneath the site. The Martinsburg Formation is composed of alternating layers of shale and lithic sandstone, and minor limestone interbeds. Seismic refraction data indicate that the bedrock surface slopes toward the Shenandoah River (ERM 1993), and that erosional features (bedrock depressions) are present on the top of the bedrock in several locations onsite. ERM (1993) hypothesized that a bedrock depression near Sulfate Basin 2 indicates a weaker zone in the bedrock, possibly caused by fracturing, that may influence the direction of migration of the dense carbon disulfide plume.

In addition, many parts of the site contain disposed wastes, such as viscose and fly ash, from the rayon-fiber manufacturing process. Some of the waste disposal facilities were excavated below pre-existing grade to increase facility storage capacity, and appear to extend below the groundwater table. Many of the deeper wastes in these basins are at least partially saturated with water, and they may exert a localized influence on groundwater flow.

For the purposes of vertically profiling groundwater conditions, previous investigators have classified groundwater monitoring wells in four different depth zones at the site: overburden, and shallow, intermediate, and deep bedrock (Figure 2-7). Shallow bedrock is defined as extending from the top of the bedrock to 100 ft below ground surface. The intermediate zone lies from 100 to180 ft deep, and the deep bedrock is defined as more than 180 ft deep. These distinctions are arbitrary and are not based on any physical separation in flow between the zones. Some site wells span more than one zone.

Structure — The geology of the bedrock has a significant influence on the movement of groundwater and the chemicals of concern beneath the Avtex site. As described previously, regional compression of the Valley and Ridge province resulted in a northeast–southwest trending system of folds (synclines and anticlines) in bedrock in the vicinity of Front Royal. An anticline has been mapped in the Martinsburg Formation to the northwest of the site. The strike of the fold axis varies somewhat between N20E and N30E (Figure 2-6; Rader and Biggs 1975). A stereonet plot of the measured strike and dip of the bedrock along the fold axis of the anticline indicates that the anticline plunge is approximately 10° to the southwest, with a range of 0 to 20°. Projection of the strike of the anticline fold axis to the southwest intercepts the viscose basins and the wells in Rivermont Acres that have exhibited carbon disulfide contamination (as will be described in Section 3.2). Structural measurements on bedrock immediately west of the Rivermont Acres wells provide further evidence for the continuity of the anticline across the Shenandoah River (Figure 2-6).

In this area, Rader and Biggs (1975) measured beds dipping 55° to the northwest, while approximately 0.1 mile to the southeast, the beds dip 15° to the southeast, indicating that the axis of an anticline runs between these beds. Cleavage tends to form parallel to the fold axis, and the dense carbon disulfide plume migrates along these cleavage-controlled fractures that parallel the anticline fold axis (see Section 3.2).

2.5.2.3 Groundwater Elevations and Flow Directions

The South Fork of the Shenandoah River is a regional groundwater discharge feature. At the Avtex site, the groundwater gradient in the overburden and bedrock units is westerly, toward the river. Similarly, across the river to the west, water levels measured in wells indicate a groundwater gradient toward the river to the east. Figures 2-8, 2-9, and 2-10 show the groundwater potentiometric surface and generalized groundwater flow directions in the overburden and shallow and intermediate bedrock. In the overburden, groundwater flow will be perpendicular to the groundwater potentiometric surface contours, as indicated by the arrows on Figure 2-8. However, in aquifers with anisotropic hydraulic conductivities (i.e., where the horizontal conductivity varies with direction), groundwater flow may not be perpendicular to the potentiometric contours. Because the hydraulic conductivity of the bedrock appears to be significantly higher parallel to the bedrock strike than in other directions, particularly along the anticline fold axis, groundwater flow paths in the bedrock will be skewed toward the direction of higher hydraulic conductivity, which may not be perpendicular to the groundwater potentiometric surface. These flow paths are likely oriented more to the southwest, along strike, than to the west, as would be interpreted from the groundwater potentiometric surface (Figures 2-9 and 2-10).

Comparison of water levels in wells near the facility basins indicates a downward vertical gradient from the basins and overburden into the shallow bedrock. This downward gradient is particularly pronounced near the viscose basins and sulfate basins, which are partially saturated with water, resulting in localized mounding of the water table. Immediately along the bank of the Shenandoah River, hydraulic gradients are upward. For example, vertical gradients measured in overburden/shallow-bedrock well clusters near the river (004/104, 017/117, 005/105, 010/110, and 011/111) in April 1994, averaged 0.13 ft/ft upward. The upward gradients along the riverbank are consistent with discharge of groundwater from the overburden and shallow bedrock to the river.

2.5.2.4 Aquifer Parameters

Overburden --- ERM conducted slug tests in 16 overburden monitoring wells. These tests provide an estimate of horizontal hydraulic conductivity in the overburden, which ranged from 1.5×10^{-5} cm/sec to 5.6×10^{-3} cm/sec, with a geometric mean of all tests of 2.0×10^{-4} cm/sec (0.6 ft/day). Based on the slug test data, the hydraulic conductivity of the overburden may be slightly higher along the river bank than farther east of the river. ERM (1999) reports that the average horizontal hydraulic conductivity value for overburden wells along the river is 1.1×10^{-3} cm/sec (3.1 ft/day). The vertical hydraulic

conductivity of the overburden has been measured in the laboratory on samples collected by Halliburton/Gannett Fleming (1993), ERM (unpublished data), and GeoSyntec Consultants (GeoSyntec 2000). Values ranged from 9.9×10^{-6} to 9.1×10^{-9} cm/sec (2.8×10^{-2} to 2.5×10^{-5} ft/day), with a geometric mean of 8.2×10^{-8} cm/sec (2.3×10^{-4} ft/day). These vertical hydraulic conductivity measurements are 2 to 3 orders of magnitude lower than the horizontal hydraulic conductivity values, and are low enough to impede vertical migration of water and site chemicals.

Bedrock --- The hydraulic conductivity of the bedrock is related to the number of fractures present and the aperture of those fractures. A large number of single-well hydraulic conductivity measurements have been made in the bedrock, and these data are summarized in Appendix B. ERM conducted slug tests in 52 bedrock wells, and pressure packer tests in 45 bedrock wells, to measure hydraulic conductivity within specific vertical intervals. The geometric mean of all horizontal hydraulic conductivity (K) values obtained in the shallow, intermediate, and deep bedrock zones was 1.1×10^{-4} cm/sec (0.31 ft/day), 1.3×10^{-4} cm/sec (0.36 ft/day), and 6.5×10^{-5} cm/sec (0.18 ft/day), respectively. In comparison to the clay overburden, in which K varies over two orders of magnitude, the range in measured hydraulic conductivity values in the bedrock is five to six orders of magnitude (Appendix B). This is expected for fractured bedrock, because high hydraulic conductivities are typically observed in highly fractured zones, and the unfractured zones exhibit lower hydraulic conductivities.

The response of the bedrock aquifer to pumping has been characterized by constant-rate pumping tests conducted in wells PW01 and PW03 (Geraghty and Miller 1988), and by "counter-pumping" that was undertaken to reduce migration of the plume. In addition, ERM conducted a pumping test at well 316 (ERM 1994, unpublished data).

The Geraghty and Miller pump tests included a large number of observation wells on both the east and west sides of the river. Transmissivity (the product of hydraulic conductivity [K] and aquifer thickness) and storage values ranged from 0.074 to 1.13 ft^2/min (107 ft^2/day to 1627 ft^2/day), and from 3.2×10^{-5} to 9.7×10^{-3}, respectively. Geraghty and Miller's estimated transmissivity values were relatively consistent throughout all the wells. In particular, transmissivities determined from the test were similar along the bedrock strike and at angles to the strike (i.e., Kx=Ky). However, drawdowns were much larger along strike than cross strike, indicating that the system is anisotropic (i.e., hydraulic conductivity values are higher in one lateral direction than in another [Kx>Ky]). Anisotropy in the bedrock system influences groundwater flow and migration of site chemicals.

ERM (1994) found that the pumping test results for well 316 (located between viscose basins 9 and 10, and on the fold axis of the anticline) were not representative of an isotropic medium. Thus, they analyzed the data assuming an anisotropic medium. They estimated the effective transmissivity at 710 gpd/ft (95 ft^2/day), with an anisotropy ratio of transmissivity along strike versus across strike (K_x:K_y) of at least 10,000 to 1. Thus, transmissivity may be on the order of 71,000 gpd/ft (9,500 ft^2/day) along strike, and only

7.1 gpd/ft (9.5 ft^2/day) perpendicular to strike (ERM 1994, unpublished data). It is not clear whether this bedrock anisotropy ratio is representative of conditions throughout the site, or only in the vicinity of well 316 (along the anticline fold axis).

If bedrock anisotropy occurs across the site, it would suggest that groundwater flow lines will not necessarily be perpendicular to the groundwater equipotential lines (Figures 2-9 and 2-10), and would in fact be toward the southwest rather than toward the west. Groundwater flow directions are not presented on Figures 2-9 and 2-10, because it is unclear how laterally extensive the observed anisotropy is at the site. ERM also estimated a storage coefficient of 6.5×10^{-4} from this test (unpublished data).

2.5.2.5 Estimated Groundwater Velocities

Groundwater velocities, V_{gw}, in the overburden can be estimated using the equation:

$$V_{gw} = Ki/n$$

where K = hydraulic conductivity, i = hydraulic gradient, and n = effective porosity.

Using the geometric mean K of 2×10^{-4} cm/sec (0.6 ft/day) in the overburden, the observed gradient, i, in the overburden of 0.03 (based on April 1994 water levels; Figure 2-8), and an effective porosity of 0.30 for clay materials (de Marsily 1986), the groundwater velocity is approximately 21 ft/yr. Given the variability in measured values of K throughout the site, this value should be considered an order-of-magnitude estimate.

Making similar groundwater velocity estimates for the bedrock is appropriate only if the bedrock groundwater system approximates an equivalent porous medium. Using the geometric mean hydraulic conductivity for the shallow, intermediate, and deep bedrock (see discussion above, 0.31 ft/day, 0.36 ft/day, and 0.18 ft/day, respectively), a bedrock porosity of 0.04 (an intermediate value within the range of 0.005 and 0.075 reported for shales; deMarsily 1986) and a gradient of 0.03 (based on April 1994 water levels; Figures 2-9 and 2-10), the groundwater velocity in the shallow, intermediate and deep bedrock is estimated to be 86, 99, and 50 ft/yr, respectively. However, given the fractured and anisotropic nature of the bedrock, it is unclear whether the assumption of an equivalent porous medium is reasonable. Groundwater velocities may be significantly higher within fracture zones (primarily oriented parallel to bedrock strike), and lower within the less fractured portions of the bedrock.

2.5.3 Surface-Water Hydrology

The primary surface-water feature at the Avtex site is the South Fork of the Shenandoah River. Surface water from the Avtex site generally drains toward the river, which has historically received runoff and WWTP discharges from the site (Section 2.2). The surface-water component of this work plan is limited to the Shenandoah River and stormwater runoff, and any seeps associated with viscose basins 9, 10, and 11. Other

onsite surface-water issues will be handled under the closure actions for the operable units in which they are located.

The South Fork of the Shenandoah river flows northeast to its confluence with the North Fork. The average streamflow measured at the U.S. Geological Survey's gaging station, located approximately 1,000 feet upstream of the site (station number 01631000), is 1,600 cfs, with maximum and minimum discharges of 114,000 and 107 cfs, respectively, from October 1, 1930 to September 30, 1998. Based on the USGS topographic quadrangle, the normal stage of the river adjacent to the site is approximately 470 ft amsl (above mean sea level).

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3. Conceptual Site Model

This section presents a conceptual site model that describes the origin and evolution of contamination related to OU-7 at the Avtex site. The conceptual site model is our current understanding of the mechanisms that control the release of site chemicals from potential source areas to groundwater, and the subsequent transport and fate of the site chemicals in the groundwater system. This understanding forms the basis for the supplemental site characterization (Section 6) that is required to support the FS and for the development of remedial action alternatives.

3.1 Nature and Extent of Contamination

A substantial volume of data has been collected to characterize the environmental conditions and the nature and extent of contamination at the Avtex site. The primary site characterization efforts include the initial RI investigation conducted in 1987 by Geraghty and Miller for Avtex, and the RI investigation conducted by ERM in 1993 and 1994 for FMC. The majority of the data collected during these efforts have been compiled into a single, GIS-based database, which is the primary source of the following evaluation of the nature and extent of contamination.

More than 1400 samples from 112 monitoring wells have been analyzed to characterize groundwater chemistry. Table 3-1 presents a summary of all the groundwater data collected at the Avtex site, including the number of analyses performed for each chemical, the frequency with which the chemical was detected, and the maximum concentration detected and the location and date of the maximum concentration measured. The highest concentrations of site chemicals typically occur within a zone of high-salinity, high-pH groundwater that extends southwest from the vicinity of viscose basins 9, 10, and 11 along the geologic strike of the anticline that underlies the site (Section 2.5.2.2) to beyond the Shenandoah River. Carbon disulfide is the most prominent site chemical in this zone of groundwater. This zone of groundwater is hereafter referred to as the "dense carbon disulfide plume" because of its high (salinity-derived) density and carbon disulfide content. Several trace metals are also present at elevated concentrations within the plume. The occurrence of site chemicals in groundwater outside the plume is generally infrequent and limited to relatively low concentrations.

3.1.1 Potential Source Areas

The following section identifies and evaluates facilities at the Avtex site that represent potential sources of site chemicals to groundwater. Viscose basins 9, 10, and 11 have been implicated repeatedly as the primary source areas (Geraghty and Miller 1988;

Halliburton/Gannett Fleming 1993; ERM 1994), and Exponent's analysis below confirms this finding. As a result, these basins are discussed in the most detail.

3.1.1.1 Viscose Basins 9, 10, and 11

Viscose basins 9, 10, and 11 received waste viscose produced from the rayon manufacturing process from 1958 to 1983. The waste viscose material contained within the basins has a basic pH and high levels of carbon disulfide, metals, and dissolved salts---constituents that were consistently present in groundwater samples collected from monitoring wells located southwest (i.e., downstrike) of the basins within the dense carbon disulfide plume.

Physical Configuration and Properties --- Viscose basins 9, 10, and 11 were probably excavated close to, if not into, bedrock, and berms were built up around the excavations. Viscose basins 9, 10, and 11 are estimated to contain 3.3, 3.8, and 2.7 million cubic feet of viscose sludge, respectively (i.e., a total of 363,000 cubic yards). Borehole data indicate that a thin layer of overburden exists beneath most of the viscose sludge in basins 9 (thickness of 1–5.5 ft) and 10 (thickness of >3 ft), and portions of basin 11 (thickness of 0–8 ft). The berms around the three basins extend to an elevation of 526 to 530 ft above mean sea level (amsl). The viscose sludge fills the basins to an elevation of 515 ft amsl in basins 9 and 10, and 519 ft amsl in basin 11. Sludge thickness within the basins ranges from approximately 20 ft in viscose basins 9 and 10 to approximately 15 ft in viscose basin 11. The upper 1–2 ft of the sludge in each of the basins consists of a crust layer of desiccated sludge.

Overburden water levels are approximately 15 ft above the bottom of the viscose sludge in viscose basins 9 and 10, and approximately 5 ft above the bottom of the sludge in viscose basin 11. The potentiometric surface of the bedrock aquifer is at approximately 5 ft to 10 ft above the bottom of the sludge in basin 9, 2–3 ft above the bottom of sludge in basin 10, and is approximately at the bottom of the sludge in basin 11. During the 1987–88 field activities, Geraghty and Miller installed piezometers in viscose basins 9 and 11, and confirmed that portions of the sludge in viscose basin 9 were below the groundwater surface, but they were unsure as to whether the soils beneath the basin were saturated, or whether a direct hydraulic connection existed between the basins and groundwater (Geraghty and Miller 1988).

The consistency of the viscose sludge is primarily highly viscous and gelatinous, but a small percentage is hard and rubber-like. In 1988, samples of the sludge were analyzed for a variety of geotechnical parameters. The sludge is not a soil, and many of the soil property tests could not be performed because the material would not mix with water, could not be cut, and did not hold its shape (Geraghty and Miller 1988). The sludge is hydrated, containing over 80 percent bound water. The viscose sludge is relatively impermeable, with core samples yielding vertical permeability values in the range of 10^{-7} cm/sec ($10^{-3.5}$ ft/day) (ERM 1994). As a result, the majority of fluid flow through the sludge likely occurs along the interface of adjoining blocks and along fractures in the

sludge. Core samples will not provide representative measurements for this type of macroscopic flow, and the vertical permeability measured in these cores will likely be underestimated.

Chemical Properties --- Table 3-2 presents a general summary of all the chemical data collected for viscose sludge samples from basins 9, 10, and 11, including the number of analyses performed for each chemical, the frequency with which the chemical was detected, the maximum concentration reported, and the location and date of the maximum concentration. Carbon disulfide, phenol, and several trace metals were detected frequently in the viscose sludge samples. Detected carbon disulfide concentrations ranged from 0.015 to 20,000 mg/kg. The lowest concentrations in each basin were detected in the surficial crust material. Concentrations generally ranged from 1 to 1,000 mg/kg in the waste viscose underlying this crust layer, and tended to decrease slightly at the bottom of the basins, near the overburden/viscose interface. Phenol concentrations ranged from 0.13 to 15,000 mg/kg, and demonstrated a depth-wise distribution similar to that of carbon disulfide. Several metals were detected in the samples of viscose sludge, the most prominent of which were iron, lead, and zinc.

Toxicity Characteristic Leaching Procedure (TCLP) tests were conducted on borehole samples from viscose basins 10 and 11. TCLP data were available for arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver (data not shown). None of these metals exceeded the regulatory limits that would require classifying the viscose sludge as a hazardous waste. The TCLP extracts were not analyzed for organic constituents.

In addition to collecting solid viscose sludge samples, fluid samples were collected from piezometers installed in basins 9 and 11 during the 1987 RI investigation, and from the seep at viscose basin 10 during the 1993 RI investigation. These fluid samples had elevated pH levels (10–12), specific conductivity, and TDS (Table 3-3). TDS concentrations in these samples ranged from approximately 26,000 to 46,000 mg/L in pore-water samples from viscose basins 9 and 11, respectively. The primary chemical constituents in the fluid samples were carbon disulfide, methylene chloride, acetone, phenol, and toluene. The major ion composition of basin-fluid samples was evaluated using a trilinear diagram (Piper 1944)[1]—indicating that the fluid samples were sodium bicarbonate to sodium bicarbonate/sulfate waters (Figure 3-1).

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[1] The major ions present in most waters include the cations calcium, sodium, magnesium, and potassium, and the anions sulfate, chloride, carbonate, and bicarbonate. Waters are often classified in terms of their dominant cation and anion (e.g., a water with the dominant ions sodium and bicarbonate would be classified as a sodium bicarbonate water). Calcium data were not collected for these samples, and Figure 3-1 assumes that the contribution of calcium to the overall water quality of the samples is small relative to sodium. This assumption is supported by the lack of elevated calcium concentrations and the strong sodium signature in the plume water (see Release Mechanisms, below).

Groundwater Chemical Distribution --- Groundwater monitoring has defined the presence of a groundwater zone---the dense carbon disulfide plume---characterized by substantially elevated concentrations of carbon disulfide, high salinity (or TDS), high pH, and elevated concentrations of trace metals. The plume appears to originate from the vicinity of viscose basins 9, 10, and 11 and extends southwesterly to beyond the South Fork of the Shenandoah River (Figure 3-2). The distributions of pH, carbon disulfide, and arsenic observed in groundwater samples from site monitoring wells are plotted on a geologic cross section oriented along the plume centerline (Figure 3-3 [oversized plate]) and along the eastern and western banks of the Shenandoah River (Figure 3-4 [oversized plate]). In the immediate vicinity of viscose basins 9, 10, and 11, the plume occurs in overburden groundwater and in all three depth zones of the bedrock aquifer. However, southwest of the basins, the plume is primarily limited to wells completed within the intermediate and deep depth zones of the bedrock aquifer. At the Shenandoah River, the width of the plume in the intermediate depth zone is approximately 500 ft.

Groundwater samples from monitoring wells in the vicinity of viscose basins 9, 10, and 11, and within the dense carbon disulfide plume, are typically sodium bicarbonate to sodium bicarbonate/sulfate waters with elevated TDS concentrations. As shown in Figure 3-5, the major ion composition and TDS concentration of the groundwater samples collected from within the dense carbon disulfide plume strongly resemble those of the viscose basin pore-water samples. These similarities are evident across all three depth zones in monitoring wells located in the immediate vicinity of viscose basins 9, 10, and 11, as well as in intermediate and deep wells located along the plume axis (e.g., wells PW02, GM06, 205, 215, and 305).

TDS concentrations of groundwater within the dense carbon disulfide plume are on the order of 50,000–100,000 mg/L, which is 50 to 1,000 times greater than in upgradient groundwater, and more than twice the TDS of sea water. An extrapolation of the relation between salinity content and density (Wetzel 1983) indicates that the density of the plume water in the vicinity of the viscose basins would be 4 to 7 percent greater than background groundwater (calculation not shown). This denser plume water would tend to sink through the bedrock aquifer along vertical and inclined fractures in the bedrock. The TDS concentrations tend to decrease in groundwater samples collected along the downstrike direction of the plume axis. In shallow bedrock wells, substantially elevated TDS concentrations are apparent only adjacent to viscose basins 9, 10, and 11 (Figure 3-6). Intermediate bedrock monitoring wells contain elevated TDS in downstrike wells, but the concentrations generally decrease with distance from the viscose basins (Figure 3-7). Deep monitoring wells 316 and 305, which are located in the plume, also have elevated TDS concentrations (Figure 3-8). The spatial trend of TDS in the bedrock aquifer suggests that the plume is sinking as it migrates toward the river on a southwesterly axis that parallels regional structural features (i.e., folds and fractures) in the bedrock aquifer.

Concentrations of carbon disulfide detected within the plume range from several hundred parts per billion (μg/L) to a maximum of 5,100 mg/L---detected in a sample collected

from intermediate-bedrock well GM08[2] in May 1987—and demonstrate the same general distribution as TDS concentrations (see Figure 3-2). Carbon disulfide concentrations were highly elevated (i.e., >500 mg/L) in groundwater samples collected from overburden well MW09 and shallow bedrock wells MW03 and 116, which are located immediately adjacent to viscose basins 9, 10, and 11 (Figure 3-2). Carbon disulfide concentrations generally decrease substantially (typically to <1 mg/L) in overburden and shallow bedrock wells located both downgradient and downstrike of viscose basins 9, 10, and 11, although carbon disulfide concentrations were slightly elevated (concentrations ranging from 0.57 to 8.9 mg/L) in well 177—a shallow bedrock well located west of the Shenandoah River.

Carbon disulfide was found to be present at elevated concentrations in groundwater samples from several intermediate bedrock monitoring wells. Groundwater samples collected from wells 216 and GM08, located immediately adjacent to viscose basins 9, 10, and 11, contained maximum carbon disulfide concentrations of 150 and 5,100 mg/L, respectively. Carbon disulfide concentrations were also elevated (10 to >100 mg/L) in intermediate wells 205, GM06, PW02, GM02A, and GM02B, which are located downstrike of viscose basins 9, 10, and 11 and generally define the centerline of the plume. Carbon disulfide concentrations were slightly elevated (1.4–8.4 mg/L) in groundwater samples collected from well 215, located west of the Shenandoah River. The plume width is well characterized in the immediate vicinity of the river due to the extensive well coverage in this area. Groundwater containing more than 1 mg/L of carbon disulfide (the EPA risk-based concentration [RBC] for tap water for this chemical) spans an approximate width of 800 ft (i.e., in a north-south direction) in this area.

The carbon disulfide plume has been detected at a depth of 300 ft bgs in well 305—the deepest well completed within the plume. The maximum carbon disulfide concentration measured in this well was 500 mg/L. The deep bedrock monitoring well 316, which is collocated with shallow and intermediate bedrock monitoring wells 116 and 216 immediately adjacent to viscose basins 9, 10, and 11, also exhibited elevated concentrations of carbon disulfide (140–360 mg/L). Carbon disulfide concentrations were 0.031 (B)[3] mg/L or less in groundwater from the deep-bedrock monitoring well 315, which is located west of the Shenandoah River close to the apparent leading edge of the plume.

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[2] A carbon disulfide concentration of 310,000 mg/L was reported for a May 1987 groundwater sample from well GM-2B. However, this value appears to be incorrect, and may be an error in reporting units (mg/L instead of μg/L). Re-testing of the same sample resulted in a concentration of 270 mg/L—a level that is consistent with the measured carbon disulfide concentrations in samples collected from the same well 10 weeks later. Furthermore, this lower concentration is within the range of concentrations observed in nearby wells completed within the plume.

[3] The data qualifier "B" signifies that the analyte was not detected substantially (10 times) above the level reported in the laboratory or field blanks (includes field, trip, rinsate, and equipment blanks).

Several trace metals---such as antimony, arsenic, nickel, chromium, and mercury---also occur at elevated concentrations within the dense carbon disulfide plume. The occurrence of antimony, arsenic (Figure 3-9), and nickel within the plume is consistent with that of carbon disulfide (i.e., elevated concentrations of these metals extend southwest from the vicinity of viscose basins 9, 10, and 11 to the Shenandoah River). Concentrations of these metals in samples from wells completed within the plume were typically 100–2,000 μg/L. Elevated concentrations of chromium and mercury (typically 2–200 μg/L) tend to be detected only within the dense carbon disulfide plume in monitoring wells located immediately adjacent to viscose basins 9, 10, and 11 (e.g., wells MW03, MW09, 116, and 216).

Release Mechanisms --- Waste viscose consists primarily of sodium cellulose xanthate, wherein carbon disulfide is chemically bound within the solid matrix of the waste viscose. The term "xanthate" describes the bond between the carbon of carbon disulfide, and hydroxyl ligands on the cellulose (cellulose is a polymer of glucose units). As the waste viscose ages, cellulose xanthate slowly decomposes, releasing carbon disulfide from the waste viscose matrix (see Appendix A). This process will continue until all of the cellulose xanthate has decomposed, or until the viscosity of the material increases to the point where the release of carbon disulfide becomes diffusion limited and ceases. The total mass of carbon disulfide may not be reflected by the measured concentrations of carbon disulfide in samples of the waste, because conventional analytical measures of carbon disulfide in solid samples may not account for carbon disulfide bound to the cellulose. As a result, the true carbon disulfide source potential represented by the viscose waste remaining in the three basins is uncertain.

Other site chemicals present in the waste viscose are likely adsorbed to the organic surface of the waste viscose, and may also be non-specifically incorporated within the waste viscose matrix. Although the viscose wastes contain high concentrations of many of the site chemicals associated with the dense carbon disulfide plume, samples of viscose wastes from viscose basins 9, 10, and 11 did not contain substantially elevated concentrations of arsenic and antimony (Table 3-2)---both of which co-occur with the dense carbon disulfide plume. It is possible that the basins are not the primary source of these metals, but rather that these metals are solubilized from soil and aquifer solids by high-pH leachate from the basins.

Waste viscose is a gelatinous material with little interconnected porosity and low permeability. As such, movement of water through the waste likely occurs primarily along the interface of adjoining blocks of waste (areas of different permeability) and along fractures within the sludge. Much of the waste viscose deposited in viscose basins 9, 10, and 11 is below the overburden water table, and limited data suggest that the water table is mounded within the basins (Geraghty and Miller 1988). The basin berms limit the ability for precipitation to run off from the basins, thus increasing the potential infiltration of water into the waste viscose. Although the hydraulic connection between the basins and the bedrock aquifer is not completely understood, borehole data indicate

that portions of the basins (particularly basin 11) rest directly on the bedrock surface—suggesting a direct connection with the bedrock aquifer.

Pore waters within the viscose basins are highly concentrated in carbon disulfide, several trace metals, and dissolved solids. The high salinity of the basin pore water provides a density gradient for vertical migration through the bedrock aquifer. The dense water in the basins essentially sinks through the bedrock aquifer—carrying site chemicals with it. This process may be augmented by a vertical hydraulic gradient resulting from the mounding of water within the basins. Under current site conditions, the release process will continue as long as appreciable amounts of salts and site chemicals are present in the basin pore waters. Given that the potential carbon disulfide source (i.e., residual bound carbon disulfide) is not well characterized, this process could continue for an unknown duration.

3.1.1.2 Plant Area

As described in Section 2.4.1, the main plant building housed the entire rayon manufacturing process, and thus, several chemicals were either stored or handled in this area. Table 3-4 lists the different plant facilities described in Section 2.4.1 and summarizes the primary chemicals that may be present within each area. Chemicals in soils adjacent to and underlying these plant area facilities can be mobilized by infiltrating meteoric water and travel vertically to the overburden water table. Density effects such as those observed in the dense carbon disulfide plume emanating from viscose basins 9, 10, and 11, are not anticipated to be significant in the plant area. Therefore, any chemicals released from the plant area would be anticipated to occur primarily in overburden groundwater.

Groundwater data immediately downgradient/downstrike of the plant area are limited to the samples collected from bedrock monitoring wells 103, 107, 203, 207, and 303. Groundwater samples from these wells have not contained elevated concentrations of inorganic or organic chemicals. A few metals were detected at slightly elevated concentrations in an unfiltered ("total") groundwater sample collected from well 303 in February 1994, but were substantially lower in the filtered ("dissolved") sample from the same sampling event. However, data are limited downgradient of the plant, and additional investigation will be required to assess whether the plant area is a source of site chemicals to groundwater.

The plant area will be addressed under a separate closure action, and any soils that could pose a risk to groundwater quality will be analyzed further and remediated, as necessary. However, impacts to groundwater and any groundwater remedies (if necessary) will be evaluated as part of this FS.

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3.1.1.3 WWTP and Sulfate Basins

The primary function of the WWTP was to neutralize acidic discharge from the Avtex facility. Hydroxide sludge produced from the acid-neutralization process was disposed of in the WWTP's emergency lagoon and three polishing basins, and in the sulfate basins (Figure 2-5). The emergency lagoon and polishing basins PB-01 and PB-02 occupy approximate areas of 18, 11, and 13 acres, respectively. The surficial site contours indicate the presence of a third polishing basin, PB-03, west of PB-02. This basin is fully vegetated and is estimated to occupy an area of 13 acres. The sulfate basins consist of six surface impoundments that cover approximately 85 acres and are estimated to contain 936,000 cubic yards of sludge.

The WWTP and sulfate basins are believed to have been constructed by excavating soil from the basins and using the excavated soil to form berms. The sludge is predominately zinc hydroxide, with minor amounts of zinc sulfate, zinc carbonate, gypsum, cellulose, iron hydroxide, and metal oxides. The emergency lagoon is estimated to have a sludge thickness of 11–14 ft, and an approximately 3-ft-thick overburden layer separates the sludge from the bedrock aquifer. Borehole data for polishing basins PB-01 and PB-02 indicate that these basins have a sludge thickness of approximately 5 ft, and have little to no overburden separating the sludge from the bedrock. Individual sulfate basins are estimated to have a sludge thickness between 5 and 25 ft, except for basin 5, which ranges from 1 to 6 ft thick. A layer of overburden separates most of the sludge in the sulfate basins from bedrock; it is estimated to range in thickness between 2 and 16 ft, except in basin 5, where a portion of the sludge sits directly on bedrock (ERM 1999a).

The 1999 EE/CA for closure of the sulfate and WWTP basins found that the basins do not represent a substantial source of site chemicals to groundwater (ERM 1999a). The primary constituents present in samples of the basin sludge were cadmium, chromium, copper, lead, and zinc. Furthermore, the EE/CA concluded that metals are not readily leached from the sludge based on an evaluation of groundwater quality data from overburden and shallow bedrock monitoring wells, and TCLP data on the basin sludge. Organic chemicals were detected infrequently in the sludge samples, indicating that the sludge is not a substantial source of these chemicals to groundwater. The EE/CA did conclude, however, that the sulfate and WWTP basins are a limited source of TDS to groundwater.

At present, freeboard is maintained on the basins (i.e., a layer of water is maintained on the surface), which ensures saturated conditions within the sludge and may increase the hydraulic gradient in the overburden between the basins and the Shenandoah River. Closure of these facilities, as described in the EE/CA (ERM 1999a), will involve draining surface water from the basins, and capping and contouring. These actions will substantially decrease fluid flow through (and thus chemical loading from) the basins to groundwater, and should eliminate further TDS loading to groundwater.

3.1.1.4 Viscose Basins 1–8

Viscose basins 1 through 8 were used for the disposal of waste viscose from 1940 through 1958. These basins were closed by covering them with contoured soil caps and re-vegetating. As discussed previously, the old solid waste landfill existed above basins 4, 5, and 6 and was subsequently closed by liquid dewatering, contouring, capping, and hydroseeding. The basins are estimated to contain a combined total of 175,000 cubic yards of viscose sludge. Boring logs indicate that these basins were probably constructed by limited excavation, and that native overburden exists to varying degrees below the waste viscose in each basin. Data indicate the following overburden-layer thicknesses beneath these basins: basins 1, 2, and 3 (1–5 ft thick); 4 and 6 (0.5–7 ft thick); and 7 and 8 (1–10 ft thick). Boreholes in basin 5 indicate that a portion of the viscose sludge sits directly on bedrock.

Measurement of water levels in wells in the vicinity of viscose basins 1–8 indicates that the overburden water table adjacent to the basins is below much of the waste viscose that is deposited in these basins. However, piezometers installed in basins 1, 2, 3, and 7 indicated saturated conditions within the basins, suggesting potential local mounding of water within the basins. It is not known whether the water observed in these basins represents perched water or if saturated conditions exist between the basins and the overburden groundwater system. No water level data are available within basins 4–6; however, because basins 4–6 are constructed in a manner similar to basins 1, 2, 3, and 7, it is probable that they too contain mounded water. Infiltration of meteoric water to basins 1–8 probably is less significant than it is to basins 9–11, because basins 1–8 have been capped with soil, contoured, and revegetated. As a result, less water is likely to move through the basins to underlying groundwater. In addition, several of the basins have a substantial thickness of overburden underlying the waste viscose, which may limit the hydraulic connection between the basins and the underlying bedrock aquifer.

In general, samples of waste viscose from basins 1–8 contained somewhat higher metals concentrations, but much lower VOC concentrations, including carbon disulfide, than did samples from basins 9, 10, and 11. Average carbon disulfide levels in viscose basins 1–8 are more than 300 times less than in basins 9, 10, and 11. The limited concentrations of carbon disulfide in viscose basins 1–8, coupled with the basins' probable low degree of hydraulic communication with the bedrock aquifer, suggests that basins 1–8 are not a substantial ongoing source of site chemicals to groundwater. Furthermore, overburden monitoring wells MW-11 and MW-12, which are located downgradient of viscose basins 1–6 and 7–8, respectively, have not exhibited substantially elevated concentrations of site chemicals.

Viscose basins 1–8 are a component of OU-10, which will be addressed under ROD-4. Any remedial actions implemented under ROD-4 are likely to reduce any potential future release of site chemicals from these viscose basins to groundwater.

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3.1.1.5 Fly-Ash Basins and Stockpile

The fly-ash basins consist of four fly-ash surface impoundments and the fly-ash stockpile. The fly-ash basins and stockpile were used for disposal of fly ash generated by the onsite coal-fired power plant. It is believed that the basins were constructed by excavating soil from the basins and using it to form the berms. Fly ash was placed in fly-ash basins 1, 2, 3, and 6, and the former fly-ash basin 4, which was located beneath the fly-ash stockpile (Figure 2-5). The fly ash in the stockpile is material that was removed from the fly-ash basins. As stated previously, fly-ash basin 6 was originally a sulfate basin that was converted to a fly-ash basin.

Analytical results from previous studies indicate that the key constituents in the fly-ash basins and stockpile are metals typically found in coal combustion fly ash. Metals, including arsenic, selenium, and thallium, have been detected frequently in fly-ash samples, while the detection of organic compounds has been infrequent and at low concentrations. Two overburden (012 and 013) and three shallow-bedrock (112, 113, 114) monitoring wells are located immediately downgradient/ downstrike of the fly ash basins. Groundwater samples from these wells generally have not shown elevated concentrations of site chemicals, indicating that the fly-ash basins and stockpile are not a significant source of site chemicals to groundwater. Samples collected from overburden monitoring well 014, which is located on the eastern side of fly-ash basin FA-03 (Figure 2-7), have been found to contain elevated concentrations of arsenic (approximately 1 mg/L in filtered samples). However, well construction logs indicate that this well is screened within the basin fly-ash material, and thus, the samples from well 014 are not representative of overburden groundwater quality downgradient of basin FA-03.

3.1.1.6 New Landfill

Solid wastes have been received at the new landfill since 1983. The landfill contains an estimated 54,000 cubic yards of material. A lined collection system collects and conveys leachate from the landfill to the WWTP. As such, the new landfill is not likely to present a threat to groundwater. This conclusion is supported by the lack of site chemicals in groundwater samples collected from monitoring wells MW7 and MW8, which are located immediately downgradient of the new landfill (Figure 2-7).

3.1.2 Summary of Groundwater Conditions

Exponent's evaluation of the available groundwater data for the Avtex site is consistent with the findings of previous site investigations. The dense carbon disulfide plume associated with viscose basins 9, 10, and 11 represents the primary component of groundwater contamination at the site. In addition to carbon disulfide, groundwater in the plume is of high pH, and contains elevated levels of TDS, phenol, pH, antimony, arsenic, nickel, and, to a lesser extent, chromium and mercury.

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The available data suggest that, while other site facilities may be sources of dissolved solids to groundwater, they are not likely to be significant sources of metals or organic contaminants to groundwater. Although occasional groundwater samples from wells downgradient of some of the facilities have shown slightly elevated concentrations of certain site chemicals (most frequently metals), these occurrences are typically infrequent and do not appear to indicate a primary source area. However, additional data are necessary to fully evaluate whether the plant area represents a significant source of chemicals to groundwater.

A few pesticides—including aldrin, α- and γ-chlordane, dieldrin, and heptachlor—and the SVOC bis(2-ethylhexy)phthalate (BEHP) were detected at slightly elevated concentrations in several site monitoring wells. These detections were generally sporadic in nature, and thus are inconsistent with a groundwater plume originating from any particular source area. These findings are consistent with the fact that there is no record of pesticide use at the Avtex site beyond typical pest control applications. BEHP, although potentially present in limited quantities associated with vacuum pump usage at the site, was not used in a manner that would be consistent with the broad and sporadic distribution of the BEHP detections in groundwater at the site. The majority of the BEHP detections (59 percent) were qualified due to the detection of BEHP in laboratory and/or field blanks—suggesting that the detection of BEHP in site groundwater samples may be related to laboratory and/or field contamination. This hypothesis is supported by the fact that elevated levels of BEHP were detected in several of the background monitoring wells.

3.2 Transport and Fate of Site Chemicals in Groundwater

This section identifies the mechanisms that govern the transport and fate of chemicals released from viscose basins 9, 10, and 11, into overburden and bedrock groundwater at the Avtex site, and discusses the potential pathways for human or ecological exposure to these chemicals.

3.2.1 Migration in the Subsurface

In the overburden, any lateral migration of dissolved chemicals from the viscose basins would occur in the direction of groundwater flow, as determined from the groundwater potentiometric surface (Figure 2-8). With the exception of MW09, which is located immediately adjacent to viscose basin 9, high concentrations of carbon disulfide have not been detected in the overburden, indicating that the lateral migration of site chemicals from the viscose basins is minimal. It is probable that the high density of the leachate in the viscose basins has resulted in primarily vertical migration of viscose-derived leachate into the underlying bedrock.

Chemical migration in the bedrock generally is associated with the dense carbon disulfide plume (Figure 3-2). Migration of the plume is to the southwest, in the direction of bedrock strike, whereas the general direction of the groundwater flow gradient is to the

west, toward the Shenandoah River. Carbon disulfide as a free product is more dense than water; thus, it would be expected to sink in groundwater. Although it is clear that the carbon disulfide plume at the Avtex Fibers site is moving in response to density effects, it is not clear whether the carbon disulfide in the plume is present as a free product, in which case it would be a dense non-aqueous phase liquid (DNAPL), or dissolved in saline groundwater, in which case it would be a constituent of a dense aqueous-phase liquid (DAPL). The process that created the viscose at the site would have resulted in dissolved carbon disulfide in the viscose that was deposited in the basins. Thus, the carbon disulfide that is present in the plume probably occurs as a dissolved constituent in the saline water that was released from the basins. However, it is possible that small quantities of free carbon disulfide were also discharged to the basins, and that some DNAPL was released to the groundwater as well. In either case, the movement of the carbon disulfide plume is controlled by density effects, and the presence of either DNAPL or DAPL would result in a long-term source of carbon disulfide to groundwater. More specifically, factors that control plume migration would include the volume of leachate discharged from the viscose basins, the time duration of the release, the properties of the leachate (density being the most important), the orientation and aperture of the fractures in the bedrock, and the hydraulic gradient. After being released from the viscose basins, gravitational forces have caused the plume to migrate vertically into the bedrock. The angle of descent appears to have been quite steep, because high TDS and carbon disulfide concentrations are present at a depth of 230–250 ft bgs in well 316, located adjacent to viscose basins 9, 10, and 11 (Figure 3-2).

The dense carbon disulfide plume appears to have migrated vertically and horizontally along fractures and bedding planes in the bedrock. The extent and intensity of the fractures at depth are not known, but may be sufficient that the bedrock approaches an equivalent porous medium. It is probable that the plume is migrating along cleavage-controlled fractures parallel to the strike of the anticline's fold axis (Figure 2-6), and that this fracture system controls the direction of migration. In addition, because the plunge of the anticline is toward the southwest, bedding-plane fractures may also provide a pathway for density-driven movement of the plume. The lack of substantial plume-related chemical concentrations in shallow-bedrock monitoring wells located downstrike of the viscose basins suggests that significant vertical migration of the plume is occurring near the viscose basins, and that the lateral migration of the primary plume mass is occurring at depth. Furthermore, the gravitational forces driving the plume have been sufficient to overcome the hydraulic gradients at the Shenandoah River, allowing the plume to migrate below and beyond this regional groundwater divide. Historical pumping of domestic wells at Rivermont Acres may have enhanced the migration of the plume beneath the river.

The dense carbon disulfide plume will continue migrating until counterbalancing forces stop it. The most likely counterbalancing force is the higher hydraulic head in the ridge to the southwest of Rivermont Acres (Figure 3-3 [oversize plate]). The force balance and potential for future migration of the plume will be analyzed as part of this FS.

The migration rate of the dense carbon disulfide plume in the subsurface can be estimated empirically from the theoretical travel times for plumes from the viscose basin sources to the Rivermont Acres domestic wells. Carbon disulfide was first detected in the Rivermont Acres wells in 1982 (Geraghty and Miller 1988). Because no complaints were registered prior to 1982, it is assumed that significant concentrations of site chemicals were not present in water pumped from those wells before that year. Using the known times at which each of the viscose basins began receiving wastes, and the distance between the basins and the Rivermont Acres wells, the travel time for the leading edge of the plume between the basins and the wells can be estimated. These calculations assume that carbon disulfide is not attenuated by degradation or sorption. It is also assumed that carbon disulfide moves as a slug in the groundwater (i.e., dispersion is insignificant). Travel times for vertical migration of the plume from the basins to the bedrock are not included in these estimates.

Horizontal transport velocities from viscose basins 9 and 10 to the Rivermont Acres wells are estimated to be 93 and 90 ft/yr, while the migration rate from viscose basin 11 is significantly higher, 297 ft/yr. The only scenario in which the estimated plume migration rate could have been 297 ft/yr is one in which the carbon disulfide contamination observed in Rivermont Acres wells in 1982 was derived solely from viscose basin 11. If the plume migration rate was, in fact, 297 ft/yr, and the plume was released from any viscose basin other than basin 11, carbon disulfide would have been observed in the Rivermont Acres wells much earlier than 1982. It is probable that all three of the basins contributed to the dense carbon disulfide plume, and under this more likely scenario, the plume migration rate is estimated to be 90 ft/yr.

3.2.2 Fate of Site Chemicals

Site chemicals can be attenuated in groundwater by abiotic and biotic mechanisms. Common mechanisms include adsorption to aquifer surfaces, precipitation reactions, abiotic decay, volatilization, and biodegradation. The primary chemicals of interest are those associated with the dense carbon disulfide plume—namely carbon disulfide, arsenic, antimony, chromium, nickel, and mercury. Carbon disulfide is subject to all of these attenuation mechanisms, except precipitation reactions. The trace metals generally will be attenuated only by adsorption and precipitation reactions.

3.2.2.1 Carbon Disulfide Attenuation

The principal carbon disulfide attenuation mechanism in the bedrock aquifer is hydrolysis (abiotic decay); the other attenuation mechanisms are relatively unimportant. Carbon disulfide has a low tendency to adsorb (Howard 1994), so its movement is unlikely to be significantly retarded by adsorption to aquifer materials. Volatilization will be significant only near the surface of the viscose basins, and while carbon disulfide biodegradation has been reported in a limited number of studies (Abou-Rizk et al. 1995; Hokanson et al. 1990), it is not likely to be significant under the relatively extreme conditions present in the site groundwater (e.g., high pH and TDS).

During hydrolysis, carbon disulfide reacts with hydroxyl ions (OH^-) in water to produce bicarbonate and hydrogen sulfide according to the following reaction:

$$CS_2 + 3OH^- \Rightarrow HCO_3^- + 2HS^-$$

The hydrogen sulfide produced from this reaction may react with cationic metals in groundwater to form insoluble sulfide minerals (Section 3.2.2.2). Excess hydrogen sulfide would likely react with hydroxyl ions to produce sulfate and water. These reactions will depend on the chemical conditions of the groundwater (e.g., pH, redox).

The rate of carbon disulfide hydrolysis depends on the concentrations of both carbon disulfide and OH^- (i.e., the reaction rate is second order)[4] (Elliot 1990). Therefore, the hydrolysis rate increases with both increasing pH and carbon disulfide concentration, and is thus likely to be a significant degradation process in the pore waters of the viscose basins and within the dense carbon disulfide plume, where both pH and carbon disulfide concentrations are elevated. The addition of an oxidizing agent (i.e., under a treatment scheme) can further increase the hydrolysis reaction rates.

Studies of carbon disulfide hydrolysis are not numerous, and it is uncertain how rapidly hydrolysis will proceed under typical site conditions (e.g., pH 8–12, carbon disulfide concentration of 0.5–5,000 mg/L). Hydrolysis has been studied as a means of removing carbon disulfide from industrial effluent, soil, or groundwater. Most of the studies published to date have focused on carbon disulfide degradation rates in high-pH solutions, often in the presence of oxidizing agents (e.g., hydrogen peroxide) (Elliot 1990). In a 1978 document, the EPA presented a carbon disulfide hydrolysis half-life of 1 hr at pH 13 and extrapolated this and additional data to a half-life of 1.1 yr at pH 9 (EPA 1978). However, the methods and data used to derive this half-life are not cited. The actual rate of hydrolysis in site groundwater and viscose basin pore waters will be a function of the chemical composition of these waters, and it is unknown how various factors (e.g., high salinity) affect the rate of carbon disulfide hydrolysis.

Given that the carbon disulfide (CS_2) hydrolysis reaction can proceed only in the presence of high pH and elevated carbon disulfide concentrations, it is inevitable that one of these reactants will be depleted before the other. As a result, when the hydrolysis reaction rate becomes negligible, the resultant groundwater either will have high pH (due to depletion of CS_2) or will have an elevated CS_2 concentration and moderate pH.

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[4] Note that in portions of the dense carbon disulfide plume, the concentrations of CS_2 and/or OH^- may be sufficiently high that the hydrolysis reaction is, in fact, zero order (i.e., occurs at a constant rate that is independent of the concentration of CS_2 and OH^-). Furthermore, under conditions where the concentration of either of the reactants (CS_2 or OH^-) is small relative to the concentration of the other reactant, the hydrolysis reaction will be (pseudo-) first order with respect to the less abundant reactant (i.e., occurs at a rate that is proportional to the concentration of the less abundant reactant).

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3.2.2.2 Trace-Metal Attenuation

As discussed previously, several trace metals occur at elevated concentrations within the dense carbon disulfide plume, including antimony, arsenic, chromium, nickel, and mercury. The primary mechanisms that are operating to attenuate the migration of trace metals in groundwater at the Avtex site are adsorption and precipitation reactions.

Adsorption reactions are likely to be of only minor importance to the attenuation of metals in the bedrock aquifer, because fractured bedrock offers limited surface area for adsorption reactions to take place.

Precipitation reactions are strongly dependent on solution chemistry, pH, and reduction/oxidation (redox) state. Contaminated groundwaters at the Avtex site are known to have high salinity and high pH. The solubility of antimony, arsenic, chromium, nickel, and mercury will be a function of the chemistry and redox conditions of the dense carbon disulfide plume. In general, mercury and chromium occur at elevated concentrations only in groundwater adjacent to the viscose basin source areas—indicating that mineral solubility may be influencing the migration of these metals away from the basins. The solubility of mercury within the plume is likely limited by sulfide mineral formation (e.g., HgS; EPRI 1984), due to reaction of these metals with hydrogen sulfide produced during carbon disulfide hydrolysis. However, this reaction has not been verified under site-specific conditions. Any minerals that may be controlling the solubility of chromium in bedrock groundwater are uncertain. It is possible that chromium detected in groundwater near the basins is present as a soluble, hexavalent species and is reduced to an insoluble trivalent species as it migrates from the basins. However, no chromium speciation data have been collected at the site to verify this hypothesis.

The solubility of nickel may also be influenced by sulfide mineral formation. However, due to the occurrence of nickel in the dense carbon disulfide plume on the far side of the Shenandoah River, solubility controls do not appear to be substantially limiting nickel migration.

Mineral solubility constraints are not likely to exert significant control on the solubility of arsenic and antimony in the dense carbon disulfide plume. Arsenic and antimony minerals are generally highly soluble—particularly at high pH (EPRI 1984). This hypothesis is consistent with the occurrence of these metals in the plume at substantial distances from the viscose basins source area. Furthermore, as discussed previously, it is probable that arsenic and antimony present within the carbon disulfide plume were in fact mobilized from soil and aquifer materials due to leaching by the high-pH plume water.

Unlike chromium, arsenic is generally more mobile when it occurs in the reduced form (As^{3+}) relative to the oxidized form (As^{5+})—particularly under high pH conditions, under which As^{5+} is poorly adsorbed to aquifer materials (EPRI 1984). The observed mobility of arsenic relative to chromium suggests that, as anticipated, reducing conditions predominate within the dense carbon disulfide plume. However, the redox state of

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groundwater and the speciation of arsenic and chromium remain to be verified at the Avtex site, and will need to be considered when evaluating remedial alternatives for groundwater.

3.3 Potential Exposure Pathways

To understand the risk posed by site chemicals, the potential pathways for human and ecological exposure to the chemicals must be considered. The primary human health exposure pathway to site chemicals in groundwater would be through direct expsosures to groundwater from water supply wells. This would include ingestion of groundwater, direct contact with groundwater (e.g., dermal exposures), and inhalation of compounds volatilizing from groundwater. Groundwater discharge to the Shenandoah River represents the primary potential ecological exposure pathway at the site. Direct exposure to waste viscose and surface water (i.e., seep water) associated with viscose basins 9, 10, and 11 also represents a potential exposure pathway to ecological and human receptors.

3.3.1 Groundwater Discharge to the Shenandoah River

The South Fork of the Shenandoah River represents a regional and local discharge boundary for groundwater, and thus, discharge of site groundwater to the river has the potential to affect the river water and/or sediment quality. Sampling to support EPA's ecological risk assessment for the river found that metals of potential concern and VOCs were not detected in surface water, with the exception of the detection of metals in the area immediately downstream of the WWTP during periods of active operation (EPA 1999b). However, the concentrations of these metals were consistent with allowable discharge limits from the WWTP.

The conclusion that the Avtex site is not substantially influencing the water quality of the river is supported by the findings of two studies (Geraghty and Miller 1988; ERM 1999a) that used site-specific data to estimate groundwater discharge rates and concentrations, and simple mixing calculations to predict concentrations in the river. Both studies concluded that river water quality would not be degraded by groundwater discharge, primarily because groundwater flow rates are very low relative to flow rates in the Shenandoah River. Further evidence that groundwater discharge to the river is not affecting river water quality is that there is no measurable change in the river water conductivity adjacent to the site. Measured conductivity values were 0.23–0.24 mS/cm at both the reference sites and the three surface-water sampling stations adjacent to the site (U.S. EPA 1999b). Again, the exception is downstream of the WWTP during active operation. An increase in conductivity was observed immediately downstream of the WWTP (1.03 mS/cm), but concentrations decreased to 0.31 mS/cm further downstream. Water-column analyses showed no increase in pH with distance downstream, and salinity was 0.0 ppt at all points within the river. Thus, under current site conditions, groundwater discharge from the site does not affect river water quality, and closure of site facilities such as the sulfate basins should reduce loadings to groundwater and surface water even further.

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EPA's ecological risk assessment found that some metals in the sediments, including chromium, copper, lead, mercury, and zinc, pose a potential ecological risk. However, the data suggest that these metals are not associated with the Avtex site. Sediment metals concentrations do not increase with downstream distance along the site, and concentrations at the upstream reference stations are similar to those adjacent to the site, indicating that groundwater discharge from the site has not affected sediment metals concentrations. Groundwater discharge from facilities such as the sulfate basins has been ongoing for tens of years, and the river sediments and water column do not show increasing concentrations of site chemicals with downstream distance along the site. Thus, it does not appear that groundwater discharge is affecting sediment quality.

3.3.2 Human Exposure to Groundwater---Drinking Water Wells

Based on a domestic well survey conducted by Geraghty and Miller (1988), very few water supply wells in the Front Royal area are completed in the overburden, and none of the overburden wells are located downgradient (west) or downstrike (southwest) of the Avtex site. In addition, any site groundwater moving laterally in the overburden would discharge to the Shenandoah River; it would not travel past this discharge boundary. Thus, site groundwater in the overburden has no potential to affect existing domestic wells.

The Martinsburg Formation (i.e., the bedrock aquifer) is used locally for domestic water supply. The detection of carbon disulfide in domestic wells in Rivermont Acres, across the Shenandoah River from the Avtex site, in 1982, focused attention on bedrock groundwater contamination. The Rivermont Acres wells are no longer used for water supply, and the residences with affected wells are supplied with bottled water by FMC. Geraghty and Miller (1988) conducted a survey of domestic water supply wells in the Front Royal area, which identified several wells within a mile southwest (along strike) of the site. Most of these wells are unlikely to become contaminated by the dense carbon disulfide plume, for one of three reasons: 1) the well is completed at a depth above the highest elevation that carbon disulfide has been observed on the west side of the river, 2) the well is located thousands of feet away from the last detected edge of the plume, or 3) the wells are not in the direct path of the migrating plume.

Because the plume is denser than water and will therefore travel downward in the bedrock aquifer, it can be assumed that carbon disulfide is not present on the west side of the river at an elevation above that of the Shenandoah River (470 ft amsl; Figure 3-3). For the purpose of comparison, of the approximately 20 domestic wells located southwest of the Avtex site (Geraghty and Miller 1988), only six wells (numbered 131, 187, 189, 199, 201, 202) outside the Rivermont Acres area are completed at depths below 470 ft amsl. All of these domestic wells are at least ½ mile away from the Rivermont Acres wells, and from the farthest observed downstrike extent of the plume (wells 115, 215, and 315). Although it is unlikely that these domestic wells will be affected by the dense carbon disulfide plume, they represent the only potential exposure pathway for humans to the plume. Thus, the potential for migration of the carbon disulfide plume (including

mechanisms that will tend to naturally attenuate and retard the movement of the plume Section 3.2.2) to these domestic wells, and to any others in the area that have been installed since 1987, will be evaluated as part of the FS for OU-7.

3.3.3 Exposure to Viscose Basin Seepage Water

At present, seepage water from viscose basins 9, 10, and 11 is collected and treated at the site's WWTP. Potential human exposure to basin seep water during future remedial actions will be addressed under the site-wide HASP. Long-term management of seepage water, and prevention of human and ecological exposure to chemicals in the water, will be considered in the final remedy for OU-7.

3.4 Conceptual Site Model Summary

Past investigations at the site have concluded that viscose basins 9, 10, and 11 represent the primary source of site chemicals to groundwater; this study supports these findings. Groundwater monitoring has defined a groundwater plume in the bedrock aquifer underlying the viscose basins. The plume contains elevated concentrations of several chemicals, including carbon disulfide, arsenic, antimony, chromium, nickel, and mercury, as well as elevated pH levels and TDS concentrations (primarily as sodium, sulfate, and bicarbonate).

Figure 3-10 provides a schematic summarizing the important transport-and-fate elements of the conceptual model. The plume's migration is controlled by its high density, which causes it to travel rapidly in the vertical direction. The plume occurs primarily at depth (i.e., greater then 100 ft bgs) and extends southwesterly from the viscose basins to beyond the Shenandoah River. Of the metals present in the plume, only arsenic, antimony, and nickel have migrated off site; the occurrence of chromium and mercury is limited to the vicinity of viscose basins 9, 10, and 11. Outside of the dense carbon disulfide plume, site chemicals have been detected in groundwater at some locations across the site, but these occurrences are typically spatially and/or temporally isolated, are limited to relatively low concentrations, and/or are uncertain due to data quality concerns.

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4. Risk-Based Screening of Chemicals in Groundwater

The following risk-based screening of groundwater data was conducted to help focus the scope of the supplemental investigation work, so as to most efficiently collect the additional data necessary to move forward with the FS for OU-7. This analysis is not intended to supplant a formal risk assessment for groundwater, which will be prepared once the supplemental site investigation work has been completed, and will be submitted to EPA as part of the Supplemental Investigation Report.

The following risk-based screening of chemicals in site groundwater was conducted using two different methods: 1) screening of maximum concentrations against EPA Region III tap-water risk-based concentrations (RBCs), and 2) a concentration-toxicity screen, as described in the U.S. EPA document *Risk Assessment Guidance for Superfund (RAGS), Human Health Evaluation Manual Part A* (U.S. EPA 1989), to identify the most significant chemicals in groundwater at the Avtex site. The RBC screen was conducted according to EPA Region III guidance (U.S. EPA 2000b). It compared the most recent groundwater data for the site (collected by ERM in 1993/94; ERM 1994) against the most current RBC values (April 13, 2000 update). The RBCs for non-carcinogens were divided by 10 prior to performing the screen (equivalent to screening against a target Hazard Quotient [HQ] of 0.1) to account for additive effects. This evaluation indicated that 48 chemicals exceeded RBCs one or more times in groundwater beneath the Avtex site. A list of these chemicals, which include metals, organochlorine pesticides, SVOCs, and VOCs, is presented in Table 4-1; the actual RBC screen is provided in Appendix C.

The concentration-toxicity screen is intended to identify those chemicals (both carcinogens and non-carcinogens) in a particular medium that contribute most significantly to risks for a particular exposure scenario (U.S. EPA 1989)—in this case, ingestion of groundwater. To accomplish this, the maximum concentration of each chemical in groundwater was weighted by its toxicity values (Cancer Slope Factor [CSF]) and/or chemical-specific Reference Dose [RfD]; values obtained from the Region III RBC table) to provide chemical-specific risk factors. For each chemical, either the oral or inhalation toxicity data were used based on which value would yield a greater risk factor. Risk factors for chemicals were then summed (separately for carcinogens and non-carcinogens), and the relative risk for each chemical was approximated as the ratio of the chemical-specific risk factor divided by the total risk factor. The concentration-toxicity screen is presented in Appendix C. Chemicals that contributed more than 1 percent of the total risk (either as carcinogens or as non-carcinogens) were determined to be of greatest significance in groundwater. For carcinogens, the only two chemicals that contribute significantly to risk were arsenic and chromium (Table C-2). For non-carcinogens, the most significant chemicals included carbon disulfide, seven metals (antimony, arsenic, cadmium, chromium, iron, manganese, and mercury), and ammonia. The results of the concentration-toxicity screen are summarized in Table 4-1.

Comparison of the RBC screening results to those of the concentration-toxicity screen indicates that the most important chemicals in groundwater are carbon disulfide, antimony, arsenic, cadmium, chromium, iron, manganese, and mercury. Lead is added to this list because of its presence in site groundwater (lead has neither an RBC nor a toxicity value in the U.S. EPA's Integrated Risk Information System [IRIS] because of the unique manner by which HHRAs for lead are performed). These results are consistent with the chemicals known to have been used at the site and disposed of in a manner such that they had the potential to affect groundwater (see the Conceptual Site Model; Section 3). In addition, these are the chemicals that are present in the dense carbon disulfide plume that has migrated off site. These chemicals, all of which are VOCs or metals, are therefore the focus of the supplemental groundwater investigation. However, all of the groundwater data, including data for chemicals that occur less frequently and at relatively low concentrations (e.g., SVOCs and organochlorine pesticides), will be included in the risk assessment for groundwater. In addition, because minimal groundwater data are currently available downgradient/downstrike of the plant area, all potential site chemicals (i.e., metals, VOCs, SVOCs, PCBs, and organochlorinated pesticides) will be analyzed in the groundwater samples to be collected in the plant area during the supplemental investigation.

5. Feasibility Study Rationale and Objectives

The objective of the FS process is to make an informed risk management–based selection of the remedial action alternative that appears to be the most appropriate for the contaminated media of interest. The FS process involves establishing remedial goals that are protective of human health and the environment, identifying applicable regulatory requirements, identifying and evaluating potentially applicable remedial technologies, and incorporating the remediation technologies into remedial action alternatives to address all aspects of site contamination. The remedial action alternatives are then evaluated against specific criteria dealing with effectiveness, implementability, and cost to help select a preferred site remedy. Each of these components involves consideration of site-specific data and the findings of the human health and ecological risk assessments. Although the majority of the data considered during the FS are collected during the RI, the collection of additional, more focused data is usually required to further develop and refine the conceptual site model and evaluate the efficacy of specific remedial actions.

The following section identifies feasible remediation technologies by first establishing the applicable regulatory requirements and the preliminary remedial action objectives for OU-7 at the Avtex site. Established remedial technologies are then screened on the basis of site-specific conditions to identify those that are potentially applicable for achieving the remedial objectives and that comply with the regulatory requirements. This process allows for the identification of additional data that may be required to evaluate the feasibility of the most promising remediation technologies. These data needs, combined with the site characterization data gaps identified during the development of the conceptual site model (Section 3), form the basis for the scope of the additional field sampling and analyses, laboratory testing, and calculations and modeling proposed in Section 6 of this work plan.

5.1 Identification of Feasible Remediation Technologies

The feasible remediation technologies are identified through the following steps:

- Identification of potential applicable or relevant and appropriate requirements
- Preliminary identification of remedial action objectives
- Preliminary identification and screening of remedial technologies.

The following sections will step through this process for OU-7 to identify technically feasible remediation technologies for viscose basins 9, 10, and 11, and site groundwater. Further development and screening of remediation technologies, as well as the

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development and evaluation of remedial action alternatives, will be completed as part of the FS process (as described in Section 6).

5.1.1 Identification of Potential Applicable or Relevant and Appropriate Requirements

Applicable or Relevant and Appropriate Requirements (ARARs) describe the regulatory requirements and criteria that define the level or standard of control that remedial actions must obtain. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 CFR 300) and the Superfund Amendments and Reauthorization Action of 1986 (SARA) require that remedial actions achieve protection of human health and the environment. In addition, the selected remedy must comply with ARARs promulgated under federal or state law, unless a waiver is warranted. ARARs are defined as follows:

- *An applicable requirement* is a promulgated federal or state standard that specifically addresses a hazardous constituent, remedial action, location, or other circumstance at a site. To be applicable, the remedial actions or the circumstances at the site must be within the intended scope and authority of the requirement.
- *A relevant and appropriate requirement* is a promulgated federal or state requirement that addresses problems or situations similar to those encountered at a site, even though the requirement is not legally applicable.

Non-promulgated federal and state standards and policies and guidance documents are not ARARs. These are criteria to be considered (TBC) when remediating a site to protect human health and the environment. Such non-promulgated, non-binding criteria are referred to as TBC criteria.

5.1.1.1 Substantive and Administrative Requirements

Response actions conducted under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) are exempt from the administrative requirements (e.g., permits) of other environmental and public health laws, but are required to comply with the substantive requirements of those laws. In this way, substantive requirements may be applicable or relevant and appropriate, whereas administrative requirements are not. The purpose for waiving administrative requirements is to expedite the remediation of sites where normal administrative processes could pose significant delays to remedial action.

U.S. EPA guidance defines substantive requirements as those requirements that pertain directly to actions or conditions in the environment. Examples include quantitative health or risk-based restrictions on exposure to certain constituents (e.g., drinking water

MCLs), technology-based requirements for actions taken on certain constituents, and restrictions on activities in special locations.

Administrative requirements are defined as those mechanisms that facilitate the implementation of the substantive requirements of a statute or regulation; for example, the approval of, or consultation with, administrative bodies, issuance of permits, documentation, reporting, record keeping, and enforcement are all administrative requirements. It is important to understand that, while CERCLA §121(e) exempts onsite remediation activities from administrative requirements, offsite remedies are required to obtain all necessary permits and to comply with administrative requirements (U.S. EPA 1988).

5.1.1.2 Identification of ARARs

There are three types of ARARs: chemical-specific, action-specific, and location-specific. Chemical-specific ARARs are limits based on human health risk or ecological risk for specific constituents (e.g., federal and state drinking water standards). Action-specific ARARs are technology-based requirements that are prompted by the type of remedial action under consideration (e.g., National Pollutant Discharge Eliminations System [NPDES] requirements for discharges to surface water). Location-specific ARARs restrict certain activities based on the location of the site (e.g., in a wetland, floodplain, or historic site area).

ARARs were identified for OU-7 based on the conceptual site model and a review of ARARs established for the site in the Quality Assurance Project Plan (QAPP; ERM 1999b) and the Action Memorandum for Basin Closure (U.S. EPA 2000a). Tables 5-1 and 5-2 summarize the Federal and State of Virginia potential chemical-specific, action-specific, and location-specific ARARs for OU-7. Based on the selected remedial actions, some of these potential ARARs will not apply.

5.1.2 Preliminary Identification of Remedial Action Objectives

Remedial Action Objectives (RAOs) are the formal statement of the overall objectives and goals for the remedial action. The purpose of the RAOs is to ensure protection of human health and the environment. RAOs typically specify the exposure routes, receptors, and risk levels of concern. The RAOs identified for OU-7 are:

- Prevent ingestion of groundwater that presents an unacceptable risk as determined by a human health risk assessment.
- Prevent human exposures to waste viscose in viscose basins 9, 10, and 11, and to leachate generated from these basins that presents an unacceptable risk as determined by a human health risk assessment.

- Prevent ecological exposures to waste viscose in viscose basins 9, 10, and 11, and to leachate generated from these basins.

All other exposure pathways identified for viscose basins 9, 10, and 11; groundwater; and the South Fork of the Shenandoah River have been determined not to represent significant risks to human health or the environment. The Human Health Risk Assessment established that viscose basins 9, 10, and 11 are not a direct contact risk to human health, based on exposure of potential future recreators or trespassers (Gradient 1999). Although exposure to chemicals discharged with groundwater to the South Fork of the Shenandoah River represents an ecological exposure pathway, previous investigations have demonstrated that groundwater discharge is not substantially affecting background sediment or water quality in the river (Section 3.3.1).

5.1.3 Preliminary Identification and Screening of Remedial Technologies

Potential technologies that could be incorporated into remedial action alternatives for viscose basins 9, 10, and 11 and contaminated groundwater have been identified to assist in the development of the supplemental investigation program that is necessary to support the FS. These identified technologies have been screened to focus the investigations on technologies that are potentially feasible for OU-7. The following sections discuss the identification and screening process for remediation technologies for both the viscose basins and groundwater.

5.1.3.1 Viscose Basins 9, 10, and 11 Remedial Technologies

The first step in the process of identifying feasible remediation alternatives is to identify the general response actions that are applicable to OU-7. General response actions are defined as actions that, singly or in combination, will meet the RAOs defined in Section 5.1.2. The following general response actions have been identified for viscose basins 9, 10, and 11:

- Administrative controls to reduce public contact with the viscose basins
- Containment of viscose basins to prevent the migration of site chemicals to groundwater
- In-situ treatment of the waste viscose to prevent further migration of site chemicals to groundwater
- Removal of the waste viscose from the basins
- Ex-situ treatment and/or offsite disposal of the waste viscose once removed.

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These general response actions provide a basis upon which to assemble the classes of technologies that could be used for the viscose basins. For example, in-situ treatment could be performed using a biological system, a physical/chemical system, or through natural attenuation. Remediation technologies within each class were identified using the *Remediation Technologies Screening Matrix and Reference Guide,*[5] as well as the findings of previous investigations into the treatability of the waste viscose (Exponent 1998). Different remedial technologies within each of these types can then be appraised and summarily screened based on whether they are technically feasible under conditions specific to the viscose basins.

A number of previous investigations have been performed to preliminarily evaluate potential remedial technologies for the viscose basins. These studies include bench-scale laboratory investigations focusing on physical and/or chemical techniques to improve the handling characteristics of the viscose sludge (ERM 1997a,b). The results of these investigations—summarized in Table 5-3—indicated that the sludge is difficult to grind to smaller particle size and that chemical solubilization of the sludge requires addition of strong acid or base and raising its temperature. These studies also found that ex-situ biological treatment (advanced fluidized composting) was potentially highly effective at treating the sludge. In addition, a preliminary evaluation of in-situ remediation technologies was performed for viscose basins 9, 10, and 11 (Exponent 1998). This evaluation concluded that three in-situ remedial alternatives warranted further evaluation: vermiculture, electrical resistance heating (ERH), and chemical oxidation.

Remediation technologies that were screened out (i.e., eliminated from further evaluation) on the basis of technical feasibility are indicated in Figure 5-1. Examples of reasons for screening out remediation technologies for viscose basins 9, 10, and 11 are:

- In-situ bioventing, as well as in-situ and ex-situ soil vapor extraction, were screened out because air movement through the waste viscose is negligible.
- Enhanced bioremediation was screened out because no data exist to suggest that bioremediation of the waste viscose is a feasible process for remediation.
- In-situ land treatment was screened out because the consistency of the waste viscose is such that it will not support the equipment required to perform this type of remediation.
- Phytoremediation was screened out because it is not a proven technology for the type of media and chemicals present in the viscose basins.

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[5] Version 3.0 (1999), published by the Federal Remediation Technologies Roundtable, available on the Internet at http://www.frtr.gov/matrix2/top_page.html.

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- Electrokinetic separation, dehalogenation, and solar detoxification were screened out because they are not applicable to the primary chemicals of interest within the waste viscose.

- In-situ pyrolysis was screened out due to the potential for an uncontrolled release of site chemicals.

These technology evaluations are based on the previous site investigations, the properties of the site chemicals, and the findings of the conceptual site model (Section 3).

5.1.3.2 Groundwater Remediation Technologies

Using a process similar to that used for viscose basins 9, 10, and 11, feasible remediation technologies for groundwater were evaluated by first identifying the applicable general response actions. The following general response actions were identified for the groundwater and include both passive and active measures to mitigate existing and future groundwater contamination:

- Administrative controls to reduce public contact with contaminated groundwater

- Containment of contaminated groundwater

- In-situ treatment of contaminated groundwater

- Collection of contaminated groundwater

- Ex-situ treatment of contaminated groundwater after collection

- Discharge of contaminated groundwater after ex-situ treatment.

The general response actions listed above and in Figure 5-2 provide a basis upon which to assemble the classes of technologies that could be used for groundwater remediation at the site. Remediation technologies within each class were then identified using the *Remediation Technologies Screening Matrix and Reference Guide*, and were summarily screened on the basis of technical feasibility (Figure 5-2). The primary factors that will limit the feasibility of many remediation technologies are the extreme depth of the groundwater contamination (i.e., >300 ft bgs) and the geologic properties inherent to fractured bedrock aquifers. Several technologies (e.g., permeable reactive barriers, sheet piling, slurry walls, and phytoremediation) cannot be feasibly installed to a sufficient depth to intercept the dense carbon disulfide plume, while others, such as airsparging, are unlikely to be effective due to the technical infeasibility of achieving a uniform treatment (e.g., air flow for air sparging) at depth and throughout the contaminated fracture system. Examples of groundwater remedial technologies that were screened out for these reasons are:

- The use of interceptor trenches, slurry walls, grout curtains, and sheet piling was screened out because contamination extends deep into the bedrock aquifer and could not be contained by this technology.
- Phytoremediation was screened out because contamination extends deep into the bedrock aquifer, beyond the root system of the plants or trees that could be used for remediation.
- Air sparging, biosparging, and bioslurping were screened out because lateral dispersal of injected air will be limited within the fractured bedrock.

5.2 Summary of Key Data Gaps

Key data gaps have been identified to support the FS process for OU-7 at the Avtex site, based on the conceptual site model (Section 3) and the identified, feasible remediation alternatives discussed above. In general, these data gaps relate to identifying the current nature and extent of the dense carbon disulfide plume that is emanating from viscose basins 9, 10, and 11, and collecting data necessary to evaluate remedial strategies for the waste viscose in these basins. In addition, the collection of additional groundwater data downgradient of the plant is required to fully evaluate this portion of the site as a potential source of groundwater contamination. These data gaps have been categorized as site characterization data gaps and remedial action–specific data gaps. The site characterization data gaps, summarized in Table 5-4, are the additional data requirements necessary to refine the conceptual site model and thus complete our understanding of the nature and extent of the problem. Remedial action–specific data gaps represent the data necessary to evaluate the feasibility and effectiveness of remedial alternatives or combinations of technologies that may be applicable for mitigating contamination associated with viscose basins 9, 10, and 11 and site groundwater.

To identify remedial action–specific data gaps, the potentially feasible remediation technologies were evaluated and combined into remedial actions. This evaluation was performed in a preliminary manner, to identify data gaps. As described in Section 6, this evaluation will be completed formally during the FS. Remedial action–specific data gaps identified for the evaluation of in-situ and ex-situ remedial actions for viscose basins 9, 10, and 11 are summarized in Tables 5-5a and 5-5b, respectively. Remedial action–specific data gaps identified for the evaluation of remedial actions for site groundwater are summarized in Table 5-6.

Monitored natural attenuation (MNA) requires special attention due to the extensive data collection effort required to fully evaluate this technology. As indicated in Table 5-6, data gaps identified for MNA include further evaluations of the contaminant plume morphology, aquifer hydrology, and potential offsite groundwater wells that could be affected by the dense carbon disulfide plume. In addition, a series of bench-scale studies are planned to evaluate hydrolysis of carbon disulfide under site-specific conditions, and

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precipitation of cationic metals due to the production of hydrogen sulfide as a byproduct of the carbon disulfide hydrolysis reaction.

5.3 Approach to Addressing Key Data Gaps

The key data gaps identified above will be filled during the OU-7 FS process. Table 5-7 summarizes the approach that will be taken to address site characterization data gaps, and Tables 5-8a, 5-8b, and 5-9 summarize the approaches that will be used to address in-situ and ex-situ remedial action–specific data gaps for viscose basins 9, 10, and 11, and groundwater, respectively. The data gaps in Tables 5-4, 5-5a, 5-5b, and 5-6 were each assigned an identifier for use in cross-referencing to the corresponding tables that summarize the approach that will be taken to address the data gaps (Tables 5-7, 5-8a, 5-8b, and 5-9). The data gaps will be addressed by reviewing the scientific literature and site records, and conducting additional field sampling and analysis, laboratory testing, and calculations and modeling. A discussion of these activities is presented in Section 6.

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6. Scope of Work

This section presents the scope of work that will be performed to complete the FS for OU-7 at the Avtex site, including supplemental field investigations; laboratory treatability testing; field treatability testing; data evaluation, calculations, and modeling; and preparation of the FS report.

In addition to the data produced by the work described herein, the FS will also incorporate data from other site activities. Specifically, in support of the FS for OU-10 at the Avtex site, overburden monitoring wells 004, 017, 026, MW07, MW08, MW11, and MW12, shallow bedrock monitoring wells 104, 117, 118, 119, 120, and MW04, MW05, and intermediate bedrock monitoring wells GM04 and GM05 will be sampled in April 2000. These data will also be used in the evaluation of OU-7.

6.1 Project Management and Coordination

The structure of the OU-7 FS project team, and the responsibilities of the individuals on the team, are indicated in Figure 6-1. Mr. Michael Ruby will serve as the Exponent project manager, reporting directly to William Cutler, the FMC project coordinator. Mr. Ruby will be responsible for ensuring that all project activities and deliverables are completed, and for ensuring the overall quality of the project deliverables. To accomplish these goals, Mr. Ruby will rely on the task managers identified in Figure 6-1 to oversee and perform the tasks indicated.

6.2 Supplemental Field and Laboratory Investigations

This section describes the supplemental field and laboratory investigations that will be undertaken as part of the OU-7 FS to address the key data gaps identified in Section 5.2. Detailed field and laboratory methods are described in the FSAP and the Quality Assurance Project Plan (QAPP; ERM 1999b).

The supplemental field and laboratory investigations will be carried out in three phases to facilitate the timely collection and evaluation of data necessary to complete the FS. The specific elements of work to be conducted under each phase are described below and summarized in Table 6-1.

Phase I of the investigation will focus on characterization of site groundwater, and will consist of the following elements:

- Installation of 2 overburden and 6 bedrock monitoring wells

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- Installation of 14 overburden Geoprobe® temporary wellpoints
- Groundwater sampling of 67 existing and the 8 new monitoring wells, and the 14 Geoprobe® temporary wellpoints
- Performance of a residential well survey.

Phase II of the supplemental field and laboratory investigation will focus on the chemistry and hydrology of viscose basins 9, 10, and 11, and will include:

- Installation of boreholes and temporary wellpoints in viscose basins 9, 10, and 11
- Installation of overburden temporary wellpoints adjacent to viscose basins 9, 10, and 11
- Infiltration-rate testing on the surface of viscose basins 9, 10, and 11
- Single-well pumping tests in overburden and waste viscose temporary wellpoints
- Site-wide measurement of groundwater levels.
- Collection of waste viscose samples and laboratory testing of these materials
- Collection of pore water samples from temporary wellpoints in viscose basins 9, 10, and 11
- Installation of deep bedrock monitoring well 343, if necessary (see Section 3.4.4 of the FSAP).

Phase III of the site investigation will involve field treatability testing.

6.2.1 Installation of Boreholes, Monitoring Wells, and Wellpoints

Fourteen temporary wellpoints will be placed in viscose basins 9, 10, and 11, and in the overburden adjacent to the basins. These wellpoints will be used to measure water levels in the basins and in the overburden, to improve the understanding of the groundwater flow system near the basins, and to allow for collection of viscose-basin pore water for chemical analysis and laboratory testing. In addition, 8 permanent monitoring wells and 14 temporary Geoprobe® wellpoints will be installed as part of the supplemental field investigation. The purpose of these wells and wellpoints will be to:

- Characterize potential sources of groundwater contaminants in the plant area

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- Provide additional background water quality data
- Determine the downstrike extent of the plume.

A qualified professional land surveyor will survey the location, ground-surface elevation, and top-of-casing elevation of each well and wellpoint. Detailed construction methods and specifications are provided in the FSAP.

6.2.1.1 Viscose Basin Boreholes and Temporary Wellpoints

Boreholes will be installed at each of three locations in each of viscose basins 9, 10, and 11 (a total of nine locations, Figure 6-2). At each location within a basin, an initial borehole will be advanced into the waste viscose to install a temporary wellpoint, to collect samples of waste viscose for visual description, and to collect a depth-integrated composite sample of waste viscose for laboratory testing. To provide sufficient material for testing, a second, and in some locations, a third borehole will be installed at a short distance (approximately 10 ft) away from the initial borehole to collect waste-viscose samples at specific depth intervals. The laboratory testing and analyses of the waste viscose samples are summarized in Table 6-2, which includes sample requirements and, where appropriate, target sample depths. These analyses are described below:

- **Hydrologic parameters**---These material parameters will be used to estimate recharge and discharge rates to and from the viscose basins (Section 6.5.3.1).
- **Geotechnical testing**---These laboratory tests are designed to evaluate the potential for compaction (i.e., settling) and release of pore water from the waste viscose that may result from placement of an engineered cap over the viscose basins. These tests are described in Section 6.2.6.2.
- **Chemical characterization**---These chemical analyses, described in Section 6.2.6.3, will be used to evaluate the chemical release potential of the waste-viscose material.
- **Chemical oxidation tests**---As described in Section 6.3.1, laboratory tests will be performed to evaluate the efficacy of chemical oxidation for treatment of the waste viscose.
- **Vermiculture treatment tests**---These laboratory tests, described in Section 6.3.2, will be used to evaluate the feasibility of using vermiculture technology to treat the waste viscose (i.e., use earthworms to consume the waste viscose and produce inert castings).

- **Direct electrical resistance heating testing**---The feasibility of using direct electrical resistance heating to treat the waste viscose will be evaluated in these tests (Section 6.3.3).

- **Handling improvement testing**---These laboratory tests, described in Section 6.3.4, will be used to identify and evaluate chemical and physical techniques to improve the materials handling characteristics of the waste viscose.

Borehole Drilling and Sampling --- Using hollow-stem auger drilling methods, the boreholes will be advanced to the bedrock beneath the waste viscose in each basin (up to approximately 25 ft total depth below ground surface). Samples of waste viscose from the initial borehole at each location (i.e., the borehole used for installation of the wellpoint) will be collected continuously over the total depth of each borehole using a 2-inch-diameter split-spoon sampler. These samples will be used to develop a descriptive log of the color, texture, consistency, and other relevant parameters across the borehole. The samples will then be combined to form a composite sample for each borehole. Lithologic logging of any overburden or bedrock materials collected from the boreholes will be performed in accordance with the FSAP.

Specific depth-interval samples for hydrologic testing and source characterization experiments will be collected from the second borehole at each location using a 2-inch-diameter split-spoon sampler. A third borehole (one per basin) will use a 3-inch-diameter Shelby tube to collect samples of sufficient diameter for the consolidation testing. If sufficient sample material is not recovered from the second and third boreholes, additional sample material will be collected from an additional borehole installed adjacent to the boreholes already drilled. From one borehole in each viscose basin, a sample from the top of the overburden material underlying the basin will be collected and submitted for laboratory analysis of saturated vertical hydraulic conductivity. Detailed sampling and testing methods are provided in the FSAP.

Wellpoint Construction --- Temporary wellpoints will be installed in the initial borehole at three locations in each basin (Figure 6-2, Table 6-3) to collect samples of pore water for laboratory analysis (Section 6.2.2), to measure the water-table elevation in each viscose basin (Section 6.2.4.1), and to conduct single-well pumping tests to estimate the hydraulic conductivity of the waste viscose material (Section 6.2.4.2). Prior to wellpoint construction, any portion of a borehole that extends below the base of the viscose basin into overburden and/or bedrock will be backfilled with bentonite. The temporary wellpoints will be constructed using 2-inch-diameter Schedule 40 PVC casing and will be screened over the lowermost 10 ft of waste viscose using No. 10-slot (0.010-inch) screen. After construction is completed, the wellpoints will be developed and surveyed in accordance with the procedures specified in the FSAP. Locations and construction methods for these wellpoints are summarized in Table 6-3.

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6.2.1.2 Overburden Temporary Wellpoints

Temporary wellpoints will be installed in overburden at five locations in the vicinity of viscose basins 9, 10, and 11 (Figure 6-2, Table 6-3). The purpose of these temporary wellpoints is to measure the water-table elevation in the overburden adjacent to the viscose basins (Section 6.2.4.1) and to conduct single-well pumping tests to provide improved estimates of horizontal hydraulic conductivity in the overburden (Section 6.2.4.2). Together, these data will be used to better define the hydraulic relations between pore water in the viscose basins and the surrounding overburden and bedrock groundwater. This information is needed to evaluate the feasibility of several remedial approaches, including various hydraulic control strategies and dewatering options for the viscose basins.

Boreholes for the temporary wellpoints will be advanced using hollow-stem auger drilling methods to the overburden/bedrock contact. Lithologic logging of the boreholes will be performed in accordance with the FSAP. The temporary wellpoints will be constructed using 2-inch-diameter Schedule 40 PVC casing and No. 10-slot (0.010-inch) well screens. The wellpoints will be screened over the lower 10 ft of the overburden. After construction is completed, the wellpoints will be developed and surveyed in accordance with the procedures specified in the FSAP. Locations and construction methods for these wellpoints are summarized in Table 6-3.

6.2.1.3 Overburden Monitoring Well Installation

Two new permanent monitoring wells (001 and 002) will be installed in the overburden at the location shown on Figure 6-3, to evaluate background groundwater conditions upgradient (east) of the plant area (summarized in Table 6-4). The boreholes will be drilled using hollow-stem auger drilling methods, and will extend to the overburden/bedrock contact at an approximate depth of 20 to 25 ft below ground surface. The overburden wells will be constructed using 2-inch-diameter Schedule 40 PVC casing and No. 10-slot (0.010-inch) well screen. The wells will be drilled and installed as described in the FSAP.

6.2.1.4 Bedrock Monitoring Well Installation

Five wells (wells 128, 129, 130, 131, and 132) will be installed in the shallow zone of the bedrock at a depth of approximately 45 ft, and one well (well 232) will be installed in the intermediate zone of the bedrock to a depth of 140 ft (Figure 6-3, Table 6-4). The purpose of these bedrock wells is to determine water quality downstrike of the plant area, viscose basins 1–8, and the new landfill. Based on the observed direction of migration of site chemicals in the bedrock, it is assumed that migration of any chemicals released to groundwater in the plant area, from viscose basins 1–8, or from the new landfill would occur along strike, to the southwest (see Section 3.2.1). Thus, the bedrock wells will be located southwest (downstrike) of potential source areas (e.g., former carbon disulfide

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storage areas, viscose basins 1–8, new landfill), to intercept chemicals that may be migrating from these potential sources.

In addition to the wells identified above, a deep bedrock well (343; Figure 6-3) may be installed in the downstrike direction of migration of the dense carbon disulfide plume, to further delineate the leading edge of the plume. Because of access problems and the required depth of this well (approximately 330 ft), installation is expected to be difficult and costly; thus, it will be important to determine that the well is necessary before proceeding. To facilitate this decision, groundwater from existing wells on the west side of the river (115, 136, 137, 162, 177, 181, 185, 215, GM2A, GM2B, and 315) will be sampled and analyzed before proceeding with installation of well 343. These wells have not been sampled since at least 1994, and it is possible that the configuration of the plume has decreased in size or otherwise changed, and that the existing wells already constrain the leading edge of the plume. Following the groundwater sampling, the groundwater data will be reviewed and the necessity for the installation of well 343 will be evaluated in consultation with the U.S. EPA. Furthermore, if installation of well 343 is deemed necessary, the exact location of the well will be evaluated further in terms of feasibility. Because of the accessibility constraints, it is possible that well 343 will need to be located further downstrike, or further to the east (near existing well 162) of the location shown in Figure 6-3.

Bedrock wells will be installed using any combination of drilling methods needed to reach the specified depth and construct the well, in accordance with the FSAP . Preferred drilling methods include air rotary with temporary casing advance, Tubex®, or other similar methods, with conductor casing installed through the overburden. If drilling fluids are required, the only fluids that will be permitted will be air (filtered) and potable water. During drilling, rock cuttings will be logged by a field geologist to identify lithologic intervals in the bedrock. In addition, specific conductivity and pH of groundwater removed from the borehole during drilling will be monitored periodically. The shallow wells will be installed to target a depth of 45 ft below ground surface. The intermediate well will be installed to a target depth of 140 ft below ground surface.

Bedrock wells will be constructed of 2-inch-diameter Schedule 40 PVC, and screened over the depth to be monitored (35–45 ft in the shallow bedrock and 120–140 ft in the intermediate bedrock). Wells deeper than 100 ft will be constructed of Schedule 80 PVC. Locations and construction methods for these wells are summarized in Table 6-4. Detailed well construction methods and specifications are provided in the FSAP. After construction is completed, the bedrock wells will be developed and surveyed in accordance with the procedures specified in the FSAP. .

6.2.1.5 Geoprobe Temporary Wellpoint Installation

Boreholes will be installed at each of approximately 14 locations in the overburden along the western boundary of the plant area using a Geoprobe® rig. The temporary wellpoints will be installed by advancing a Geoprobe® borehole to the bedrock-overburden interface, pulling the probe rods, and installing either a temporary PVC wellpoint or a prepacked

Geoprobe® well screen. The wellpoint will be screened across the bottom 5 ft of the borehole. The soil cores produced during the wellpoint installation will be screened for organics using a photoionization dectector (PID).

These temporary wellpoints will be developed by surging and overpumping 10 casing volumes. Teflon®-lined tubing will then be connected to a peristaltic pump[6] and lowered into the wellpoint, and the wellpoint will be purged at a minimal flow rate, to keep drawdown within the wellpoint as small as possible. The purge water will be directed through a flow-through cell, and the field parameters turbidity, temperature, pH, specific conductance, dissolved oxygen, and Eh will be recorded periodically. Purging will continue until these parameters have stabilized. After purging is completed, the peristaltic pump will be used to collect groundwater samples for laboratory measurement of metals, PCBs, and organochlorine pesticides (see Section 6.2.2.2) in accordance with the FSAP. The pump intake tubing will then be removed from the wellpoint, and a stainless-steel micro-bailer will be used to collect groundwater samples for laboratory measurement of VOCs. Site chemical concentrations in these Geoprobe® sampling locations, as well as in existing and proposed wells downgradient of the plant, will be evaluated to determine whether the plant area is a source of site chemicals to groundwater. Elevated site chemical concentrations or increasing concentrations in existing wells (e.g., 103/203/303) could lead to additional investigation.

Upon completion of each Geoprobe® borehole, the temporary wellpoint will remain in place for surveying and taking water-level measurements. Water-level measurements will be made after water levels in the temporary well points have been allowed to return to static levels. After the water-level measurements have been made, the temporary wellpoint will be removed, and the borehole will be grouted.

6.2.2 Groundwater Sampling and Analysis

Selected monitoring wells and temporary wellpoints will be sampled during the FS supplemental field investigation to fulfill the following objectives:

- Determine the current spatial extent and magnitude of groundwater contamination.
- Identify potential releases to groundwater in the plant area that have not been fully characterized.
- Obtain groundwater samples for laboratory experiments (Section 6.3), and for quantification of parameters that will affect the transport and fate of site chemicals (e.g., density of the carbon disulfide plume) or

[6] Note: Sampling techniques are limited to use of a peristaltic pump and a bailer due to the limited, 1-inch diameter of the Geoprobe® wellpoints.

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the feasibility of various remediation technologies (e.g., groundwater constituents that could cause fouling of remediation systems).

The following provides an overview of the groundwater/pore-water sampling and analysis that will be performed during the supplemental field investigation. Detailed sample collection and analytical methods are provided in the FSAP.

6.2.2.1 Groundwater/Pore-Water Sampling

Groundwater from 75 permanent wells and 14 temporary Geoprobe® wellpoints, and pore water from the 9 wellpoints installed in the viscose basins, will be sampled during the supplemental field investigation. Each of the wells/wellpoints will be purged prior to sampling, according to the procedures outlined in the FSAP. Because groundwater has not been sampled at the site for six years, it is possible that some of the existing wells will require re-development prior to sampling; if it is necessary, this will be performed according to the FSAP procedures. Measurements of pH, specific conductivity, temperature, turbidity, Eh, and dissolved oxygen will be used to establish when a particular well has been adequately purged (as described in the FSAP). Once purging is complete, iron speciation will be measured and recorded.

Only one round of groundwater sampling will be conducted at this time.

6.2.2.2 Sample Analyses

The specific analyte list for each well/wellpoint (Figures 6-4 through 6-7; Table 6-5) was determined based on the occurrence (Section 3.1) and risk-based screening (Section 4) of chemicals in site groundwater. Target Compound List (TCL) VOCs and SVOCs (U.S. EPA 1994), Target Analyte List (TAL) inorganics (U.S. EPA 1996), ammonia nitrogen, and hexavalent chromium will be quantified in all samples from wells that are within and adjacent to the area of the dense carbon disulfide plume. Samples from wellpoints located within viscose basins 9, 10, and 11 will also be analyzed for TCL VOCs, TAL inorganics, ammonia nitrogen, hexavalent chromium, and chemical oxygen demand (COD). Samples will also be collected from selected wells within the dense carbon disulfide plume, and from selected wellpoints within viscose basins 9, 10, and 11 for arsenic +3/+5 speciation analysis. Samples from selected wells located downgradient of the sulfate and WWTP basins will be analyzed for TAL inorganics, ammonia nitrogen, and hexavalent chromium. Due to limited historical groundwater analytical data for the plant area, existing and proposed monitoring wells and Geoprobe® wellpoints in the plant area will be sampled and analyzed for TCL VOCs, TCL SVOCs, TAL inorganics, organochlorinated pesticides, PCBs, ammonia nitrogen, and hexavalent chromium. (Figures 6-4 through 6-7; Table 6-5). Samples will also be collected from selected wells within and upgradient of the plume, and from the wellpoints within the viscose basins, for analysis of density, alkalinity, pH, TDS, sulfate, chloride, and silica (Table 6-5). In addition, seven overburden wells and eight bedrock wells will be sampled to support the feasibility studies for both OU-7 and OU-10 (ERM 2000). Samples from these wells will

be analyzed for TCL VOCs and SVOCs, TAL inorganics, ammonia nitrogen, and hexavalent chromium.

Groundwater also will be collected from selected wells and wellpoints for use in the carbon disulfide hydrolysis tests (Section 6.2.3). For each of these studies, a total of nine replicate samples will be collected from each of wells MW03, 116, 177, 205, 215, 216, 305, and 316. These locations were selected to provide groundwater samples that are representative of the pH and carbon disulfide concentrations throughout the dense carbon disulfide plume. In addition, for each study, nine replicate samples of viscose-basin pore water will be collected from one wellpoint in each of the viscose basins (e.g., WP01, WP04, and WP07). An additional sample will be collected from these wellpoints for electrical resistivity analyses (Section 6.3.3).

6.2.3 Carbon Disulfide Hydrolysis Tests

As discussed in Section 3.2.2.1, hydrolysis is likely to be the primary mechanism for degradation of carbon disulfide present in viscose basins 9, 10, and 11, and in groundwater beneath the site. Furthermore, the presence of hydrogen peroxide substantially increases the rate of carbon disulfide hydrolysis in aqueous solutions (Adewuyl and Carmichael 1987; Elliot 1990), and thus, hydrogen peroxide could be used in a chemical treatment technology to enhance carbon disulfide hydrolysis in viscose-basin pore water and/or site groundwater. To evaluate the effects of hydrolysis on the fate of carbon disulfide in the viscose basins and in site groundwater, and to evaluate the potential efficacy of a hydrogen peroxide–based treatment approach, groundwater/pore-water samples will be collected from selected well/wellpoint locations, and the rate of carbon disulfide hydrolysis, both under site conditions (i.e., natural attenuation) and in the presence of hydrogen peroxide (i.e., "enhanced carbon disulfide hydrolysis"), will be quantified.

To evaluate naturally occurring carbon disulfide hydrolysis (i.e., in the absence of hydrogen peroxide addition), four replicate groundwater or pore-water samples will be collected from each of wells/wellpoints 116, 205, 216, 316, WP01, WP04, and WP07. These wells represent the range of pH and carbon disulfide concentrations present at the site and extend from the origin to the periphery of the dense carbon disulfide plume. The samples will be sealed under zero-headspace conditions and shipped to Columbia Analytical Services, Inc. (CAS) in Kelso, Washington. One of the replicates will be analyzed immediately upon receipt to establish the baseline concentrations (i.e., "time zero") for the laboratory experiment. The remaining samples will be stored in the dark at temperatures similar to those measured in site groundwater. A replicate sample from each well/wellpoint will be analyzed at 1, 3, and 6 months after sample collection for carbon disulfide, TAL inorganics, alkalinity, chloride, sulfate, silica, and pH. The resultant data will be used to calculate the rate of carbon disulfide hydrolysis in viscose-basin pore waters and in site groundwater, and these values will be compared to values predicted based on carbon disulfide rate constants available in the literature (Elliot 1990). Following analysis, each sample will be filtered, and if sufficient precipitate material is collected on the filter, the precipitate will be submitted to the Departmentof Geological

Sciences at the University of Colorado at Boulder for analysis by powder x-ray diffraction (XRD). This analysis will indicate whether any metal sulfides are present in the filtered solids.

Three additional replicate samples will be collected from each of the wells/wellpoints for use in the enhanced carbon disulfide hydrolysis testing. At each well/wellpoint, 0.2, 2.0, and 4.0 mL of 30 percent hydrogen peroxide will be added to the three replicate samples, and groundwater/pore water from the well/wellpoint will then be added to the vial until full and the vial will be sealed immediately. The sealed vial will then be sent to CAS for analysis of carbon disulfide, TAL inorganics, alkalinity, chloride, sulfate, silica, and pH. These data will indicate the amount of hydrogen peroxide required to facilitate carbon disulfide hydrolysis under site-specific conditions. These samples will also be filtered and analyzed by XRD, as described above.

6.2.4 Hydrology and Hydraulics

During the supplemental field investigation, several hydrological/hydraulic tests and measurements will be conducted to better characterize the site hydrology, so that effective remedial actions can be selected. Water levels in monitoring wells and wellpoints will be measured across the site to provide an understanding of the current groundwater flow regime. Single-well pumping tests will be conducted in selected overburden and viscose-basin wells/wellpoints to improve the understanding of the hydraulic properties of the overburden and waste viscose. Finally, infiltrometer tests will be conducted on the surface of viscose basins 9, 10, and 11 to improve the understanding of recharge rates to the basins and to help evaluate the overall water balance for the basins. Each of these measurements and tests is described below.

6.2.4.1 Site-Wide Water-Level Measurements

During the supplemental field investigation, water levels will be measured in all accessible existing wells and in the proposed wells/wellpoints at the site. Levels will be measured to the nearest 0.01 ft using an electric water-level indicator. Measurement of water levels will be conducted in accordance with the FSAP.

6.2.4.2 Single-Well Pumping Tests

Single-well pumping and recovery tests will be performed in three temporary wellpoints installed in the viscose basins (one each in basins 9, 10, and 11) and in four overburden monitoring wells/wellpoints, to provide estimates of horizontal hydraulic conductivity. These parameters are required to evaluate the hydraulic interactions between the viscose and surrounding overburden, and to assess the effectiveness of several potential remedial technologies for the viscose basins.

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The horizontal hydraulic conductivity of the waste viscose has not been measured previously. Hydraulic conductivity estimates have been developed previously for the overburden based on the results of slug tests, but the proposed single-well pumping and recovery tests are likely to provide improved hydraulic conductivity estimates for the fine-grained materials that are typical of the overburden.

Specific test locations will be determined after the new wells and temporary wellpoints described in Section 6.2.1 have been installed and developed. Detailed pumping-test procedures and methods are provided in the FSAP.

6.2.4.3 Infiltrometer Tests

In situ infiltrometer tests will be conducted in viscose basins 9, 10, and 11 to characterize the macro-scale infiltration properties of the basins. Due to the heterogeneity of the surface of the viscose basins, the macro-scale structural features of the waste viscose will likely control infiltration. As such, the typical approach of quantifying micro-scale material parameters in a laboratory (i.e., vertical hydraulic conductivity measurements) to evaluate infiltration would most likely produce poor estimates of the basin recharge characteristics. The results of the infiltrometer tests will be used to calculate hydraulic conductivities for the surface materials in the viscose basins, for use in estimating recharge rates into the basins using the HELP model (Section 6.5.3).

A total of nine large-diameter, single-ring infiltrometer tests will be performed. Three tests will be conducted in each basin to account for heterogeneity within the basins. The infiltrometer tests will involve driving a large-diameter (e.g., 0.5–2 m) steel ring into the ground, applying water inside the ring with a constant-head device, and taking measurements of the water supply rate until steady infiltration is observed (Maidment 1993). Locations will be selected where the steel ring can be driven to 1–2 feet below the base of the crust layer. Single-ring tests are proposed because Bouwer (*in* Wilson et al. 1995) notes that the more conventional double-ring infiltrometer tests tend to overestimate infiltration rates, so large-diameter single-ring tests are preferable. Test setup and documentation procedures will follow standard American Society for Testing and Materials (ASTM) methods (ASTM D5126-90 and D3385-94).

6.2.5 Well Survey

Water supply wells southwest of the Avtex site have the potential to be affected by the dense carbon disulfide plume. A well survey was conducted in 1987 by Geraghty and Miller (1988), which included identification of the location, total depth (where possible), and owner of all wells in the Front Royal area. As part of the FS, a second well survey, focused on the area southwest of the Avtex site (i.e., the direction of migration of the dense carbon disulfide plume) will be conducted to provide more current information on well users. Well records/permits will be reviewed to revise and update the list of water supply wells southwest of the site. Information will be obtained from sources such as the

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EPA Storet database and tax parcel data from the county health department (Figure 6-8) as to the location, owner, and total depth of each well, along with any available information on static water levels, or first water observed during drilling. A review of current aerial photographs will be used to ensure that all residences (and thus wells) are included in the well survey.

6.2.6 Waste Viscose Characterization

This section discusses the chemical and physical evaluation and field testing of waste-viscose samples collected from viscose basins 9, 10, and 11. These tests will be performed as part of Phase II of the supplemental field investigation.

6.2.6.1 Hydrologic Parameters

A total of 12 relatively undisturbed samples of waste viscose will be collected from viscose basins 9, 10, and 11 for quantification of hydrologic parameters to be used in developing the water balance for the basins (see Section 6.2.1.1). Samples will be collected in the viscose basins from the 0- to 12-inch and 12- to 24-inch depth intervals, using a split-spoon sampler equipped with stainless steel liners. The samples will be shipped under chain of custody to the GeoSyntec Consultants laboratory in Atlanta, Georgia, for measurement of field capacity, wilting point, saturated vertical hydraulic conductivity (triaxial permeability), porosity, bulk density, and moisture content. Specific methods for measuring these parameters are presented in the FSAP.

6.2.6.2 Geotechnical Testing

A total of nine relatively undisturbed samples of waste viscose, representing three different depth intervals from three different boreholes (one from each of viscose basins 9, 10, and 11), will be collected for consolidation and shear testing during the drilling of boreholes in the viscose basins (see Section 6.2.1.1; Table 6-2). These tests will be performed at the GeoSyntec Consultants laboratory by ASTM method D2435-96 and D4648-94. In the consolidation tests, the soil core is restrained laterally and incrementally subjected to increasing axial loads. The pore-water pressure is allowed to dissipate completely (i.e., the sample is allowed to drain) before the next load increment is applied. The data from the consolidation test will be used to develop the stress/strain relation of the waste viscose, to estimate the magnitude and rate of both differential and total settlement of the waste viscose beneath an engineered cap, and to evaluate the potential effectiveness of compression-based technologies (e.g., dynamic compaction) for remediation of the viscose sludge. The volume of pore water drained under each successive load increment will be recorded to provide an indication of the volume of water that would be released from the basins to groundwater under the weight of an engineered cap. During selected tests, samples of the pore water will be collected at each successive loading increment during the consolidation test and submitted for chemical analysis of TCL VOCs, TAL inorganics, alkalinity, pH, TDS, sulfate, chloride, and silica.

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In addition, samples of the viscose sludge will be collected following the completion of the testing and submitted to the analytical laboratory for the chemical characterization described in Section 6.2.6.3. The results of these chemical analyses will provide an indication of the potential for chemicals to be released from the waste viscose under compressive force.

The shear testing will involve inserting a four-blade vane into the end of the core sample and rotating the vane at a constant rate, to determine the torque required for the vane to shear the surface.

6.2.6.3 Chemical Characterization

As mentioned in Section 6.2.1.1, a total of nine samples of waste viscose, representing three different depth intervals (one immediately above and below the water table, and one at the base of the viscose) from three different boreholes (one from each of viscose basins 9, 10, and 11), will be collected for chemical characterization testing. The concentrations of site chemicals and other chemical parameters will be measured in these samples (as described below) to evaluate the extent to which the basins represent an ongoing source of contaminants to groundwater. These analyses will be performed by Lancaster Laboratories in Lancaster, Pennsylvania. Detailed methods for measuring these parameters are presented in the FSAP.

Quantification of Free and Bound Carbon Disulfide in Waste Viscose — Carbon disulfide may be present in the waste viscose, both as carbon disulfide dissolved in pore water (i.e., "free" carbon disulfide) or as carbon disulfide bound to cellulose as cellulose xanthate—referred to herein as "bound" carbon disulfide (see Section 3.1.1.1). Standard methods for measuring carbon disulfide in a solid material such as waste viscose will only quantify the "free" carbon disulfide in the material. Thus, a sequential extraction procedure will be used to quantify the concentration of carbon disulfide that is present in free and bound forms.

The sequential extraction will consist of three steps: 1) leaching of non-homogenized material in methanol; 2) particle size reduction of the resultant material, followed by leaching in methanol; and 3) leaching of the resultant material in concentrated sulfuric acid heated to 160°F. All leachates will be analyzed for carbon disulfide by Lancaster Laboratories, using standard purge-and-trap and GC/MS methods. Step 1 is the standard method that has been used to determine carbon disulfide concentrations in waste viscose during previous investigations; results of this analysis will indicate the concentration of free carbon disulfide that is readily available from the unaltered waste viscose material. Analysis of leachate from Step 2 will indicate the readily available free carbon disulfide concentration of the waste viscose once the particle size has been reduced, and results of Step 3 will provide the concentration of carbon disulfide that is chemically bound within the waste viscose. It is recognized that these sequential extractions may not liberate all of the carbon disulfide bound in the waste viscose matrix (e.g., physical force may be required to release a portion of the carbon disulfide from the matrix). This concern will

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be addressed to some extent by the consolidation tests described in Section 6.2.6.2. In addition, splits of each sample will be analyzed both prior to and following the sequential extraction by Fourier transform infrared spectroscopy (FTIR). These analyses will provide a semi-quantitative analysis of the relative abundance of carbon disulfide bound to the cellulose matrix before and after extraction, and thus provide an indication of the extraction efficiency.

Specific methods for conducting the sequential extraction and FTIR analyses are provided in the FSAP.

Waste Viscose Hydroxide Liberation Tests --- Laboratory tests will be conducted to quantify the extent to which the viscose basins represent a source of hydroxide ions to groundwater---an important component to understanding the long-term significance of hydrolysis on the fate of carbon disulfide (and, indirectly, several trace metals) in site groundwater. In addition, these tests will provide an estimate of the acid requirements necessary to neutralize the waste viscose as part of a potential future remediation alternative. As discussed in Section 6.2.1.1, a total of nine waste viscose samples will be collected during the supplemental field investigation and shipped to Exponent's Boulder, Colorado laboratory for these tests. The particle size of each of these samples will be reduced, and deionized (DI) water will be added to the sample until it is just saturated. The pH of this slurry will be recorded. The slurry will then be slowly titrated to pH 3 by periodic addition of a known volume and strength of acid. The pH of the slurry and the volume of acid added will be recorded incrementally. Following the completion of the titration, the slurry will be filtered, and the filtrate will be analyzed for TAL inorganics, chloride, sulfate, and silica.

Quantification of Other Waste Viscose Chemical Parameters --- In addition to analysis of free and bound carbon disulfide and hydroxide liberation (see discussion above), the nine waste viscose samples will be analyzed for TAL inorganics, TCL VOCs, TCL SVOCs, chloride, silica, sulfate, paste pH, chemical oxygen demand, and percent solids. Standard analytical methods, as described in the FSAP, will be used to quantify these parameters.

6.2.7 Geologic Mapping

The orientation of cleavage and bedding planes in bedrock outcrops southwest of the Avtex Site will be mapped by a geologist. In addition to mapping outcrops in the hills to the southwest of Rivermont Acres, an effort will be made to map outcrops that are exposed above the surface of the Shenandoah River during low flow. The strike and dip of the structural features in the outcrops will be used to understand the cleavage and the orientation and folding of beds, particularly with respect to the anticline that appears to provide important structural control on the movement of the dense carbon disulfide plume.

6.3 Laboratory Treatability Studies

This section identifies and outlines the general procedures for the laboratory treatability studies that are intended to evaluate the effectiveness of various remedial technologies or actions. The laboratory procedures will build upon previous laboratory testing performed for the site (ERM 1997a,b) and will consider the potential for the procedures to generate heat (and volatilize organics) and produce potentially hazardous byproducts. Before initiating these experiments, a Laboratory Treatability and Analysis Plan (LTAP) will be prepared that provides detailed experimental and quality control procedures.

6.3.1 Waste Viscose Chemical Oxidation Tests

The effectiveness of using various chemical oxidants, such as hydrogen peroxide, Fenton's Reagent (hydrogen peroxide and iron), and potassium permanganate, for the direct chemical oxidation of the cellulose xanthate will be evaluated in laboratory batch experiments at Exponent's Boulder, Colorado laboratory. Splits of waste-viscose samples collected during the borehole installation (Section 6.2.1.1) will be homogenized to create a single composite sample. A split of the composite sample will be reserved for analyses of free and bound carbon disulfide content using the sequential extraction procedure outlined in Section 6.2.6.3, and the remainder will be subjected to chemical oxidation tests. Equal-weight portions of the composite will be placed in a series of reactors, and DI water will be added until the waste viscose is just saturated. The chemical oxidant will be added at varying percentages to the series of reactors, and the oxidant will be allowed to react with the waste viscose for 24 hours. After this period, the slurry of waste viscose in each reactor will be filtered and the residual waste viscose solids collected and weighed. The consistency of the residual solids, based on visual inspection, will be recorded, and the solids will be submitted for analysis of free and bound carbon disulfide concentrations.

6.3.2 Waste Viscose Vermiculture Treatment Tests

Initial evaluation of the vermiculture technology will involve simple bench-scale tests designed to assess 1) the ability of worms to consume the waste viscose, 2) the fate of site chemicals following vermiculture treatment, and 3) the quality of the worm castings produced from consumption of the waste viscose. These tests will be developed in conjunction with Smartworm Technology, Inc. and will be performed at Smartworm's laboratory in Mission Viejo, California. Worms will be allowed to consume a small volume of waste viscose (e.g., 5 gallons) collected during installation of the boreholes in the viscose basins. Worm survival and reproduction will be monitored, and the castings and the worms (both before and after treatment) will be analyzed for chemical concentrations (VOCs and SVOCs, TAL inorganics). In addition, the relevant parameters, such as nutrient concentrations, that would affect the quality and market value of the castings will be quantified. These data will allow for a realistic assessment

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of the marketability of the viscose-derived castings and for a determination of whether, and by how much, the sale of castings would offset the cost of remediation.

6.3.3 Waste Viscose Direct Electrical Resistance Heating Tests

The use of standard (3-phase) electrical resistance heating (ERH) technology to treat the waste viscose will be evaluated in conjunction with Applied Hydrology Associates, Inc. (AHA) of Denver, Colorado. Evaluation of ERH will involve bench-scale testing for electrical and thermal properties of the waste viscose, and for evaluation of feasibility and cost of full-scale remediation (as described in Appendix D). Sample cores of waste viscose collected during the field investigation (Section 6.2.1.1) will be sent to AHA's Calgary, Canada laboratory for analysis of electrical and thermal conductivity. In addition, samples of basin pore water will be sent to AHA's laboratory for analysis of static electrical conductivity. These data will be used by AHA to support computer modeling to evaluate the technical feasibility and cost of the ERH technology for full-scale remediation.

6.3.4 Testing of Physical and Chemical Techniques to Improve the Handling Properties of the Waste Viscose

A series of laboratory tests will be conducted at Exponent's Boulder, Colorado laboratory to evaluate the effectiveness of various chemical and physical techniques for improving the handling properties of the waste viscose, with the objective of identifying a means of excavating it from the basins and/or facilitating its treatment. The following section identifies the general tests and techniques that will be evaluated during these laboratory studies. Many of these laboratory studies will build upon the findings of previous bench-scale investigations performed on the viscose sludge (Table 6-6; ERM 1997a,b). Several of the tests proposed herein will refine/confirm the findings of the more promising techniques evaluated during the previous testing and fill any data gaps from those studies. Furthermore, additional data will be collected to evaluate techniques that were not considered previously. Detailed procedures for these tests will be provided in the LTAP.

- **Chemical solidification/stabilization:** Laboratory tests will be performed to evaluate the ability of chemical solidification and/or stabilization techniques to improve the handling characteristics of the waste viscose and/or limit the mobility of site chemicals. The tests will involve adding chemical reagents (e.g., cement, fly ash) to samples of waste viscose and evaluating the effects of the reagents on the physical properties of the waste viscose.

- **Solubilization:** Laboratory tests will be performed to evaluate various physical (e.g., heating) and chemical techniques (e.g., acidification) for solubilizing the waste viscose. The tests will involve the application of the technique to samples of waste viscose and quantifying the degree of solubilization achieved.

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- **Freezing:** Laboratory tests will be conducted to evaluate the efficacy of various freezing agents (e.g., liquid nitrogen) for freezing the waste viscose to improve its handling properties.

- **Shearing (particle size reduction):** Laboratory tests will be performed to evaluate the ability to shear the waste viscose and reduce its particle size. These tests will involve shearing the material using bench-scale shearing equipment (e.g., food processor or coffee grinder).

- **Dewatering:** Laboratory tests will be conducted to evaluate the ability to gravity drain and/or mechanically dewater the waste viscose. These tests will involve quantifying the volume of water produced from the waste using each of these methods.

- **Drying:** Laboratory tests will be conducted to evaluate the ability to dry the waste viscose, under both ambient and increased temperature conditions.

6.4 Field Treatability Studies

Field treatability studies will be conducted at the Avtex site to evaluate, on a field- or pilot-study scale, the feasibility of potentially effective remedial technologies or actions for OU-7. The remedial technologies/actions to be tested may include both in-situ and ex-situ treatment technologies and will be identified based on the results of the supplemental field investigation and laboratory treatability studies. Detailed field procedures and a quality assurance plan will be developed and presented in a Field Treatability and Analysis Plan (FTAP).

Although specific treatability studies cannot be identified at this time, it is probable that the field treatability studies will include an excavation test. This test would serve the purpose of 1) evaluating the feasibility of excavation (or removal) of waste viscose from viscose basins 9, 10, and 11, which is fundamental to all ex-situ remedial options, and 2) providing waste viscose material for field testing of ex-situ remedial actions. The excavation test would be developed based on observations made during borehole installation in the basins, the results of the consolidation and laboratory handling improvement testing, and on information gathered from interviews of vendors and construction industry professionals. The test would likely involve excavating a test pit using conventional construction equipment (e.g., trackhoe, drag line), as well as any non-conventional techniques (such as a grinder pump combined with a suction line) identified during the FS process. In addition, materials handling techniques, such as mechanical dewatering, solubilization, or stabilization, may also be evaluated in conjunction with the excavation test.

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6.5 Data Evaluation, Calculations, and Modeling

This section identifies the general data evaluation, calculations, and modeling exercises that will be performed to interpret the additional data and information gathered during the supplemental field investigation and laboratory testing. These exercises will be used to refine the conceptual site model and, ultimately, to evaluate the potential efficacy of various remedial alternatives.

6.5.1 Data Validation

A large volume of data will be gathered during the supplemental field and laboratory testing activities. These data will be evaluated according to the Data Quality Objectives described in the FSAP, and their validity will be established using the data validation procedures presented in the QAPP (ERM 1999b).

6.5.2 Evaluation of Groundwater Data

Groundwater data will be collected from overburden and bedrock monitoring wells located across much of the site and in the areas adjacent to the site that have been affected by offsite migration of site chemicals with groundwater. These data will be compiled and evaluated to establish current site conditions (e.g., distribution of site chemicals, redox conditions, and plume density) and identify temporal and/or spatial trends in the distribution of site chemicals.

Calculations, trend plots, and other evaluation tools will be used as necessary to facilitate these evaluations. The groundwater data gathered during the supplemental field investigation will also be compared against historical site groundwater data to confirm and refine previous findings and interpretations regarding the evolution and fate of groundwater contamination at the site.

6.5.2.1 Evaluation of Waste Viscose Characterization Data

Waste viscose chemical and physical data gathered during the supplemental field and laboratory investigations will be compiled and evaluated to assess the extent to which viscose basins 9,10, and 11 represent ongoing sources of chemicals to groundwater. These data will be compared to historical data to confirm previous findings and to investigate temporal changes in the waste viscose chemistry.

The results of the free and bound carbon disulfide analyses and of the hydroxide liberation tests (Section 6.2.6.3) will be evaluated to assess the extent to which the viscose basins represent a potential long-term source of these chemicals to groundwater. As described below, waste viscose hydrologic data will be used to establish the water balance for the viscose basin, while the data collected during the consolidation testing will provide insight into the capability of the waste viscose to support an engineered cap.

Calculations will be made to estimate the weight of various cap designs that might be implemented as part of the OU-7 remedial action, so that the extent of settling that is likely to occur in the basins can be evaluated.

6.5.3 Basin Water Balance

Further evaluation of several remedial alternatives requires a better understanding of the hydrologic balance in viscose basins 9, 10, and 11, and the surrounding groundwater flow system. To understand the potential reduction in the source of dense, carbon disulfide–laden water from viscose basins 9, 10, and 11 that can be achieved under various remedial alternatives, the recharge and discharge rates from the basins must be determined. In addition, the interaction between the viscose basins and the surrounding groundwater must be characterized to evaluate the potential benefit of hydraulic controls or vertical barriers as source-control measures.

6.5.3.1 Basin Recharge

The long-term recharge rate into the viscose basins will be determined using the U.S. EPA's HELP model (Hydrologic Evaluation of Landfill Performance; Schroeder et al. 1994a,b). The HELP model is a widely accepted water-balance tool that performs a sequential daily analysis of water balance components using a linked series of empirical and analytical equations. Climate data required by the model include average annual wind speed and relative humidity, daily precipitation, solar radiation, and air temperature. Data will be obtained from the onsite rain gage, or nearby meteorological station, if onsite data are not available. Required material property data include porosity, field capacity, wilting point, saturated conductivity, and initial moisture content of the viscose, which will be obtained from measurements made on intact samples. Infiltrometer testing will be used to verify and refine modeled infiltration rates under ponded conditions. Viscose material property data used in the model will be a combination of site-specific field and laboratory measurements obtained during the supplemental field investigation. Estimated recharge rates will be used to develop an overall water balance for the viscose basin under current conditions and, as appropriate, under applicable remedial alternatives.

6.5.3.2 Hydraulic Interactions Between Viscose Basins and Groundwater

To evaluate the groundwater flow system in the overburden around the viscose basins , numerical groundwater modeling will be conducted using MODFLOW (McDonald and Harbaugh 1988). MODFLOW is a pseudo-three-dimensional, finite-difference numerical groundwater flow code that is capable of simulating the important processes that govern groundwater flow in complex environments. Waste viscose and overburden material properties (e.g., hydraulic conductivity), obtained during the FS supplemental field investigation, will be used in conjunction with estimated recharge rates (described above) to develop site-specific input parameters for the model. The model will be calibrated to observed water-level measurements in the waste viscose and the surrounding overburden.

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The model will then be used to evaluate the hydraulic interactions between the viscose basins and overburden groundwater, both under current conditions and under applicable remedial alternatives for the viscose basins, including engineered caps or vertical barriers and a potential pumping system for hydraulic containment of viscose-basin leachate.

6.5.4 Chemical Migration

Data gathered during the supplemental field and laboratory testing will be used to establish the current extent of site chemicals in groundwater and to estimate the probable future offsite transport and fate of site chemicals in groundwater. These estimates will be a function of the forces that influence plume migration and the rate of attenuation of carbon disulfide and the other site chemicals, as described below.

6.5.4.1 Dense Carbon Disulfide Plume Force Balance

The movement of site chemicals in the bedrock is associated with the southwesterly migration of the dense carbon disulfide plume from the viscose basins along the geologic structural features that parallel the regional structural strike direction (Section 3.2.1). The historical migration rate of the plume, and its predicted future migration, will be evaluated by determining the balance between gravitational and hydraulic forces acting on the plume. As part of the supplemental field investigation, the density of the plume water will be measured at several locations within the plume (Table 6-5) to understand the role of hydraulic and gravitational forces acting on the migration of the plume.

Movement of the dense carbon disulfide plume beneath the Avtex site is controlled by structural features. The slope of these features ranges from small (e.g., the dip of the bedrock to the southwest) to large (e.g., vertical fractures within the bedrock). Different portions of the plume follow different flow paths---some shallow and some deep---which cause the plume to spread vertically. The slope at which a given portion of the plume migrates will affect whether it may eventually intersect any domestic wells (the receptor of concern at the Avtex site). In addition, dispersion and diffusion along the plume periphery could cause the plume to intersect domestic wells. Also, pumping could enhance migration both laterally and vertically and cause the plume to contaminate a well. The maximum slope that would cause the migrating plume to intersect a domestic well will be calculated based on the recorded depths of the wells (Section 6.2.5) and the travel distance. An opposing hydraulic gradient, provided it is large enough, can prevent the continued movement of plume along a given downward slope. The opposing hydraulic gradient required to prevent continued movement of the plume along the maximum slope that could intersect a water supply well will be calculated using equations from Cohen and Mercer (1993), and compared to observed opposing hydraulic gradients from the hills southwest of the Avtex site toward the Shenandoah River. This understanding of the gravitational and hydraulic forces acting on the plume will provide insight into the long-term migration of the plume to the southwest.

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Pumping at domestic wells could somewhat enhance migration of the plume toward the wells, extending the plume laterally or vertically. However, domestic wells would generally be pumped intermittently at low rates (a few gpm) and would thus be expected to affect the plume only where the wells are close to the plume. The potential for the plume to affect a pumping well will be evaluated using a numerical density-dependent flow model such as SUTRA (Voss 1984). It is possible that this modeling will be performed using a two-dimensional cross-sectional model. Site-specific data, such as bedrock hydraulic conductivity, will be used as input into the model. Hydrogeological uncertainty will be handled by evaluating a range of potential conditions, including variable aquifer properties, well pumping rates, and distances from the well to the plume. In addition, the model could be used to evaluate the effect of dispersion/diffusion on the chemical concentrations near the plume periphery.

6.5.4.2 Attenuation of Site Chemicals

As discussed in Section 3.2.2.1, hydrolysis is likely the most significant mechanism affecting the attenuation of carbon disulfide in site groundwater. A numerical model will be developed based on rate constants for carbon disulfide hydrolysis presented in Elliot (1990). This model will solve the second-order rate equation for carbon disulfide hydrolysis rates across the range of conditions observed in site groundwater. This model will take into account aqueous complexation and redox reactions that will limit the availability of hydroxyl ion for hydrolysis, as well as the temperature dependence of the reaction rate. The analyses described above will indicate the degree to which hydrolysis acts to degrade carbon disulfide in site groundwater. In conjunction with the CS_2 hydroloysis model described above, a geochemical model such as PHREEQC (Parkhurst 1997) will be used to model how trace metal solubility can be expected to change as carbon disulfide hydrolysis proceeds. The numerical and geochemical modeling results will be compared to the empirical data collected during the carbon disulfide hydrolysis and the enhanced hydrolysis studies. It is recognized that under certain conditions at the site (e.g., portions of the plume that contain highly elevated concentrations of carbon disulfide), the hydrolysis reaction may be a zero-order reaction. This potential phenomenon will be considered when evaluating the numeric model against the empirical data collected from the site.

6.5.5 Remedial Action--Specific Activities

This section describes the general types of activities that will be performed to evaluate the feasibility of remedial actions identified for OU-7 during the FS process. The specific activities that will be performed will depend on the remedial technologies and alternatives identified.

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6.5.5.1 Literature, Records, and Industry Review

Available literature, site and government records, and industry data will be reviewed as appropriate to identify and evaluate the feasibility of technologies and approaches for remediation of groundwater and viscose basins 9, 10, and 11. Some of the activities to be performed are listed below.

- **Review Case Studies:** Case studies of potentially effective remedial actions will be evaluated to make a qualitative assessment of the likely effectiveness of the remedial action under the conditions at the Avtex site, and to identify the potential limitations of the remedial action.
- **Contact Vendors:** Vendors of remedial technologies and equipment will be contacted to evaluate the potential efficacy and/or limitations of the technology/equipment for remediation of OU-7 media and site chemicals.
- **Contact Industry-Specific Experts:** Experts in specific fields (e.g., excavation) will be contacted to discuss and identify the potential approaches, equipment, or treatments that could be used to address the unique OU-7 conditions.
- **Review Available Site and Government Records:** Relevant records—such as residential well construction records/permits, site WWTP performance data, and previous site treatability study and/or remedial action studies—will be reviewed.

6.5.5.2 Calculations and Modeling

Several calculations and/or modeling activities will be required to support an evaluation of the feasibility, effectiveness, and cost of various remedial alternatives. Some of the likely calculations/modeling efforts include:

- **Geochemical Modeling:** Geochemical modeling using PHREEQC (Parkhurst 1997) or a similar numeric model will be performed to identify chemicals that 1) could lead to well/pump fouling during active remediation, 2) could be used for chemical grouting (either for the bedrock aquifer or the bottom of the viscose basins) and/or stabilization of the waste viscose, or 3) could be applied to the waste viscose or groundwater to attenuate site chemicals.
- **Treatment-Specific Calculations/Modeling:** The efficacy of several technologies under site-specific conditions will be evaluated through application of appropriate calculations and/or models. For example, hydraulic containment alternatives can be evaluated through groundwater flow modeling (Section 6.5.3.2), while the effectiveness

of ERH can be assessed through implementation of a model developed specifically for this purpose (see Appendix D).

- ***Application/Dosage Rate Calculations:*** *Chemical characterization* and laboratory testing data will be used to estimate the required application rates of chemicals (e.g., hydrogen peroxide, freezing agents) to treat groundwater and/or the waste viscose under various remedial actions. Application rates will be estimated over the range of conditions observed during chemical characterization and laboratory testing.

- **Estimated Remedial Process Parameters:** Appropriate calculations will be made to estimate the volume; flow rate; and chemical concentrations in waste viscose, groundwater, excavation water, and other media that will require treatment under various remedial actions.

- **Estimated Treatment Duration:** Appropriate calculations will be performed to estimate the time required to implement and complete a given remedial action.

6.6 Remedial Action Alternative Development

The purpose of the remedial action alternative development phase of the FS process is to develop the appropriate range of remedial action options to be evaluated during the detailed analysis of alternatives (Section 6.7). Remedial action alternative development comprises four components:

- Identification of remedial action objectives.
- Identification of general response actions.
- Identification and screening of remediation technologies.
- Development of remedial action alternatives.

The identification of remedial action objectives (RAOs) is the primary step in the development of remedial action alternatives. Preliminary RAOs for OU-7 were developed in Section 5.1.2 to assist in the determination of data gaps and further field investigations. The RAOs will be refined and finalized based on the findings of the supplemental investigations described previously.

General response actions describe the approaches that can be undertaken to meet the RAOs. General response actions for the remediation of viscose basins 9, 10, and 11 and site groundwater were identified in a preliminary manner in Section 5.1.3. The general response actions will be reviewed and finalized based on the findings of the supplemental investigations.

Once the general response actions that meet the RAOs are determined, classes of, and specific remediation technologies within each general response action category, can be identified. Once identified, the remediation technologies that are clearly technically infeasible under the site-specific conditions can be screened out. This screening process was completed in a preliminary manner in Section 5.1.3, and the results will be reviewed and finalized based on the findings of the supplemental investigations.

Remediation technologies that have been identified as technically feasible are then screened further based on effectiveness, implementability, and cost. These selection criteria are defined as follows:

- Effectiveness addresses the ability of the remediation technology to meet the RAOs, and considers how proven and reliable the technology is for addressing the site chemicals. This criterion considers the sensitivity of the technology to likely variables (such as volumetric changes or soil properties), and the potential impacts to human health and the environment during the installation of the technology.
- Implementability addresses both the technical and administrative feasibility of implementing a given technology. Processes requiring prohibitively extensive permitting from government agencies may be eliminated at this point.
- Cost considers both the implementation and operating costs of each remediation technology.

Through the identification and screening process, potentially applicable technologies will be narrowed to those most appropriate for OU-7 at the Avtex site.

After preliminary screening, retained technologies will be combined to create remedial action alternatives. The remedial action alternatives will be constructed so that each alternative will address all aspects of contamination at OU-7. Alternatives will include a range of containment and treatment technologies, as well as the no-action alternative. A minimum of three alternatives will be developed for detailed analysis.

6.7 Detailed Analysis of Alternatives

A detailed analysis of the remedial action alternatives will be conducted to provide the relevant information needed to select the best alternative. A specific description of each remedial alternative will be prepared and will summarize the details necessary for its implementation and operation. The following information will be provided, as applicable, for each alternative:

- Additional activities/investigations required for the implementation of the alternative

- Estimated time for remediation
- Preliminary layout of the alternative
- Conceptual design information, including flow rates and concentrations
- Sensitivity of the alternative to changes in variables (e.g., flow rates and concentrations)
- Required permits
- Identification of all action-specific ARARs.

Each alternative will then be evaluated based on the nine evaluation criteria identified by the National Oil and Hazardous Substance Pollution Contingency Plan (NCP). These criteria are described briefly below:

- **Overall protection of human health and the environment**---Alternatives will be evaluated as to whether they can adequately protect human health and the environment, in both the short and long term, from unacceptable risks posed by site chemicals associated with OU-7. Eliminating, reducing, or controlling exposure to levels established during RAO development can provide this protection.
- **Compliance with ARARs**---Alternatives will be evaluated on whether each will meet the identified federal and state ARARs. The detailed analysis will summarize the ARARs and describe how they are or are not satisfied by each alternative.
- **Long-term effectiveness and permanence**---Alternatives will be evaluated in terms of the permanence of the remedial action, along with the degree of certainty that the remedial action will be successful. This will include an assessment of the remaining risk at the conclusion of remedial activities. Also, the reliability of the controls that may be required to manage the risk posed by treatment residuals and/or untreated wastes will be evaluated.
- **Reduction of toxicity, mobility, or volume through treatment**---Alternatives will be evaluated on their ability to permanently and significantly reduce the primary risks associated with OU-7 through the destruction of the contaminants, irreversible reduction in mobility, or reduction of the total mass of contaminated media.
- **Short-term effectiveness**---Alternatives will be evaluated on the basis of short-term effects on and risks to workers, the community, or the environment during the implementation and operation of the alternative.

- **Implementability**---Alternatives will be evaluated as to the ease or difficulty of implementing the alternative considering both technical and administrative feasibility. Remediation technologies will have been screened based on this criterion earlier in the FS process; however, this evaluation will focus on comparing the relative implementability of each alternative.

- **Cost**---Alternatives will be evaluated and compared based on the basis of cost. The cost analysis will include estimation of capital costs, annual operations and maintenance (O&M) costs, and a present-worth analysis.

- **State acceptance**---Alternatives will be evaluated in the context of technical/administrative issues and concerns that the State of Virginia may have regarding each alternative; however, the acceptability of individual alternatives to the State ultimately will be determined from the State's comments on the FS.

- **Community acceptance**---Alternatives will be evaluated in terms of issues and concerns that the public may have with each; however, the acceptability of each alternative to the public ultimately will be determined through the FS public comment period.

A preferred alternative will be selected by EPA based on the results of the detailed analysis. For an alternative to be selected, it must meet the first two criteria: overall protection of human health and the environment, and compliance with ARARs. The next five criteria (long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; and cost) are balancing criteria that will be used to compare the alternatives that meet the first two criteria. The last two criteria, state and community acceptance, are modifying criteria. They will also be discussed and used to compare alternatives; however, the state and community acceptance ultimately will be determined during their respective comment periods.

6.8 Project Deliverables and Schedule

A schedule of project activities and deliverables is presented in Figure 6-9. Finalization of the FS will require 36 months from the time that the draft FS work plan is submitted to EPA for their review. It is anticipated that EPA approval to proceed with Phase I of the field investigation will be received within two months of submission of the draft FS work plan. The Phase I field investigation is anticipated to require approximately two months to complete. A Laboratory Treatability and Analysis Plan (LTAP) will be submitted to EPA for review immediately after the Phase I field investigation is completed. It is anticipated that FMC will receive EPA approval to proceed with the Phase II field and laboratory investigation within two months of completing the Phase I investigation, and that the Phase II investigation will require six weeks to complete. The entire field

program is estimated to require five and a half months to complete; however, this time estimate could increase or decrease depending on weather or other factors.

The laboratory treatability studies, initiated upon receipt of aqueous and solid samples collected during the field investigation, are anticipated to require 3 months to complete. The field treatability studies are anticipated to require 7½ months to complete, including the preparation and EPA review and approval of the Field Treatability and Analysis Plan (FTAP). The completion of this task on schedule will depend on the scope of the study, the timing of EPA's comments, and the weather once field efforts begin. Preparation of the draft FS document will take approximately four months. Finally, EPA review and response to EPA's comments, and document finalization, will require an additional 4½ months.

Four major project deliverables are required to complete the FS. The LTAP will define the procedures that will be used to complete the laboratory tests presented in Section 6.3. This plan will be delivered to EPA no later than the date of receiving approval to initiate the Phase I field investigation. The supplemental field investigation and laboratory data summary report will summarize the data collected during the supplemental field and laboratory investigations, and will present a refined conceptual site model. This report is scheduled to be delivered to EPA during the twelfth month of the project, and finalized during the sixteenth month of the project. The FTAP will be developed to define any field-scale tests that are required to evaluate possible remedial action alternatives, as determined during the supplemental field and laboratory investigations. Specific procedures for completing these tests will be presented in this plan. The FTAP will be delivered to EPA at the end of seventeenth month of the project. Finally, the draft OU-7 Feasibility Study will be delivered to EPA at the end of the thirtieth month of the project.

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Figures

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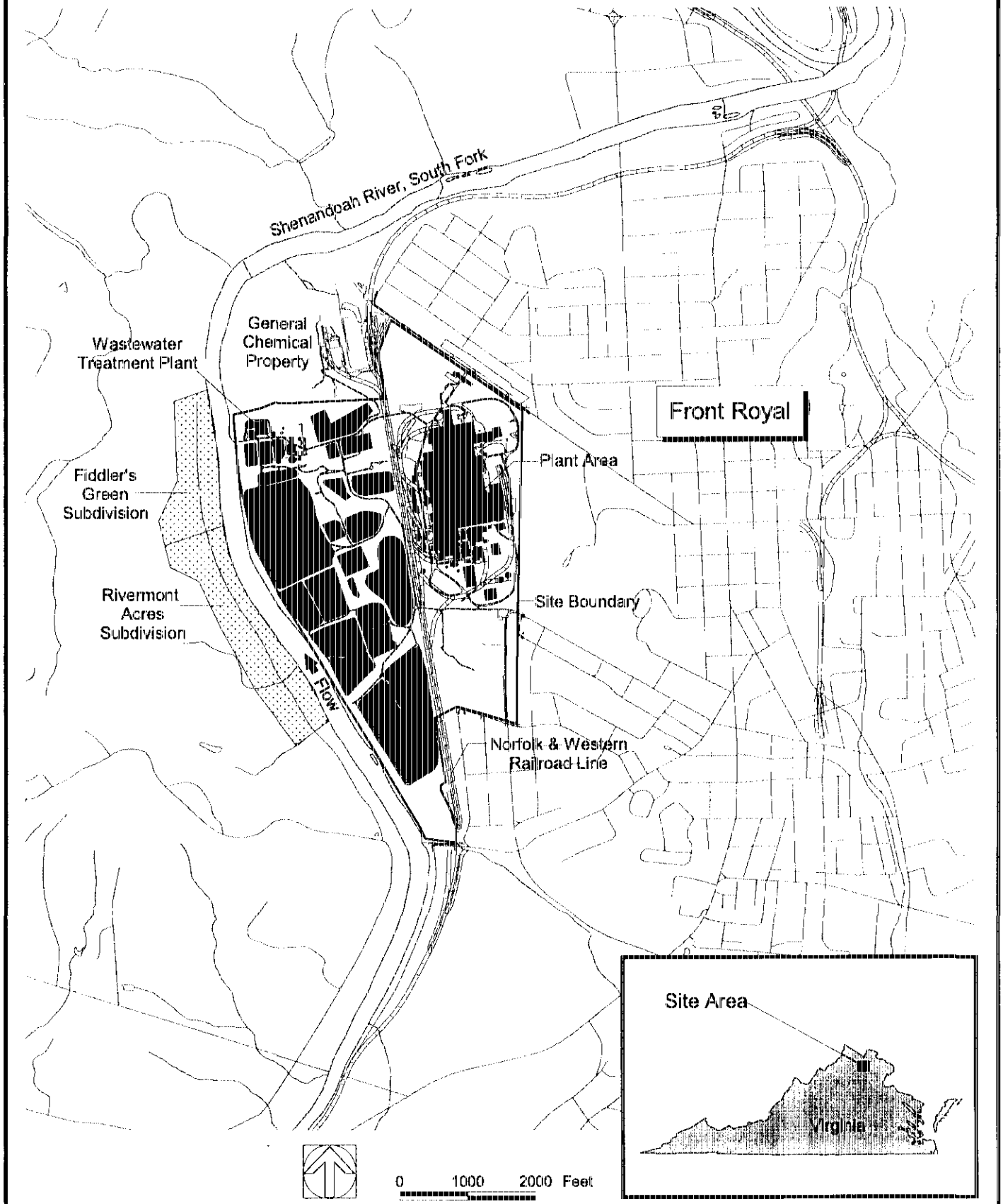

Figure 2-1. Avtex site map.

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LEGEND

Waste Area Boundary
Plant Area Boundary
Property Boundary

0 500 1000 Feet

Figure 2-2. Aerial photo of the Avtex site showing plant and waste areas (1993).

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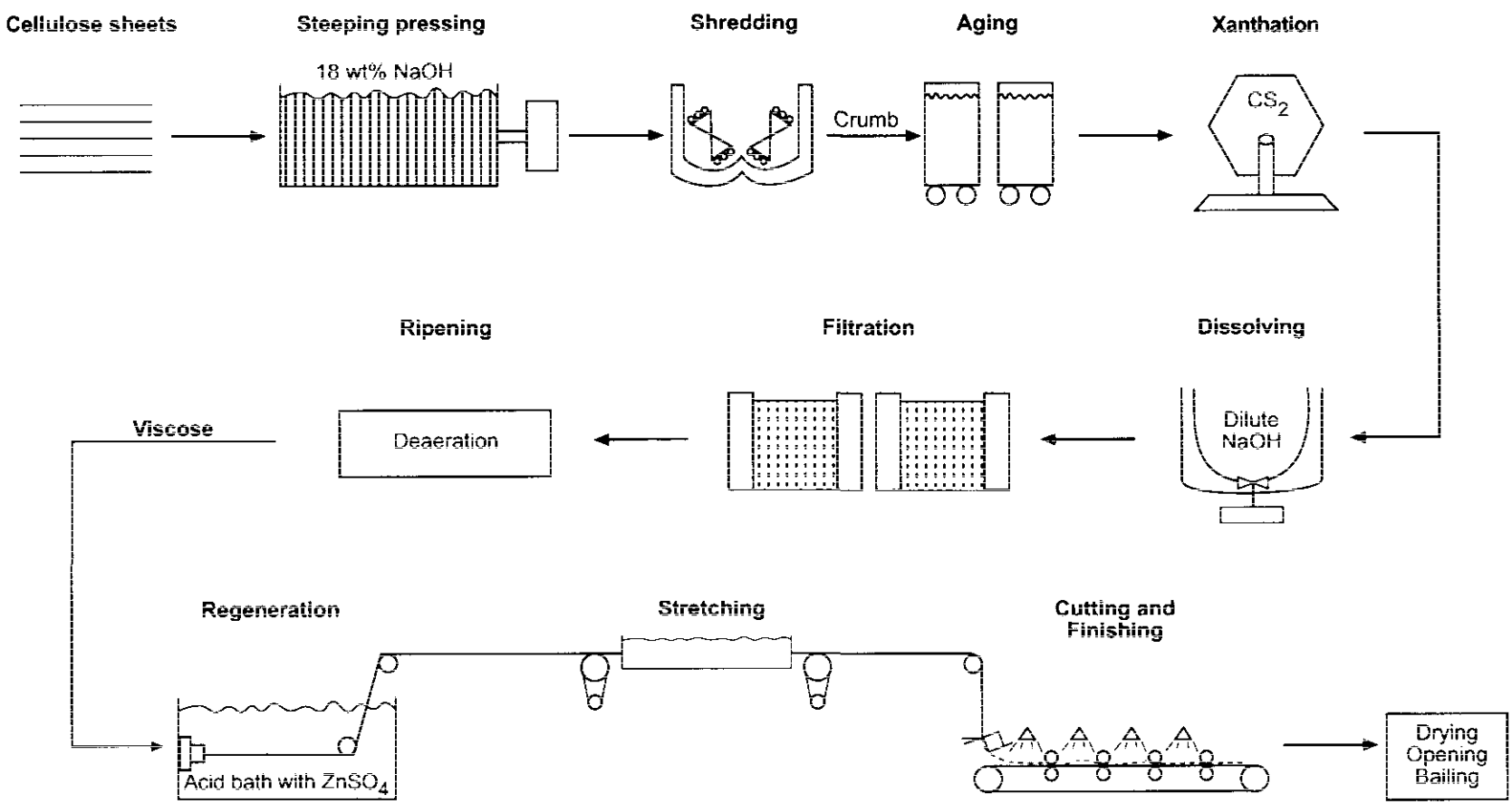

Figure 2-3. Conceptual schematic of the viscose process (adapted from Grayson 1985).

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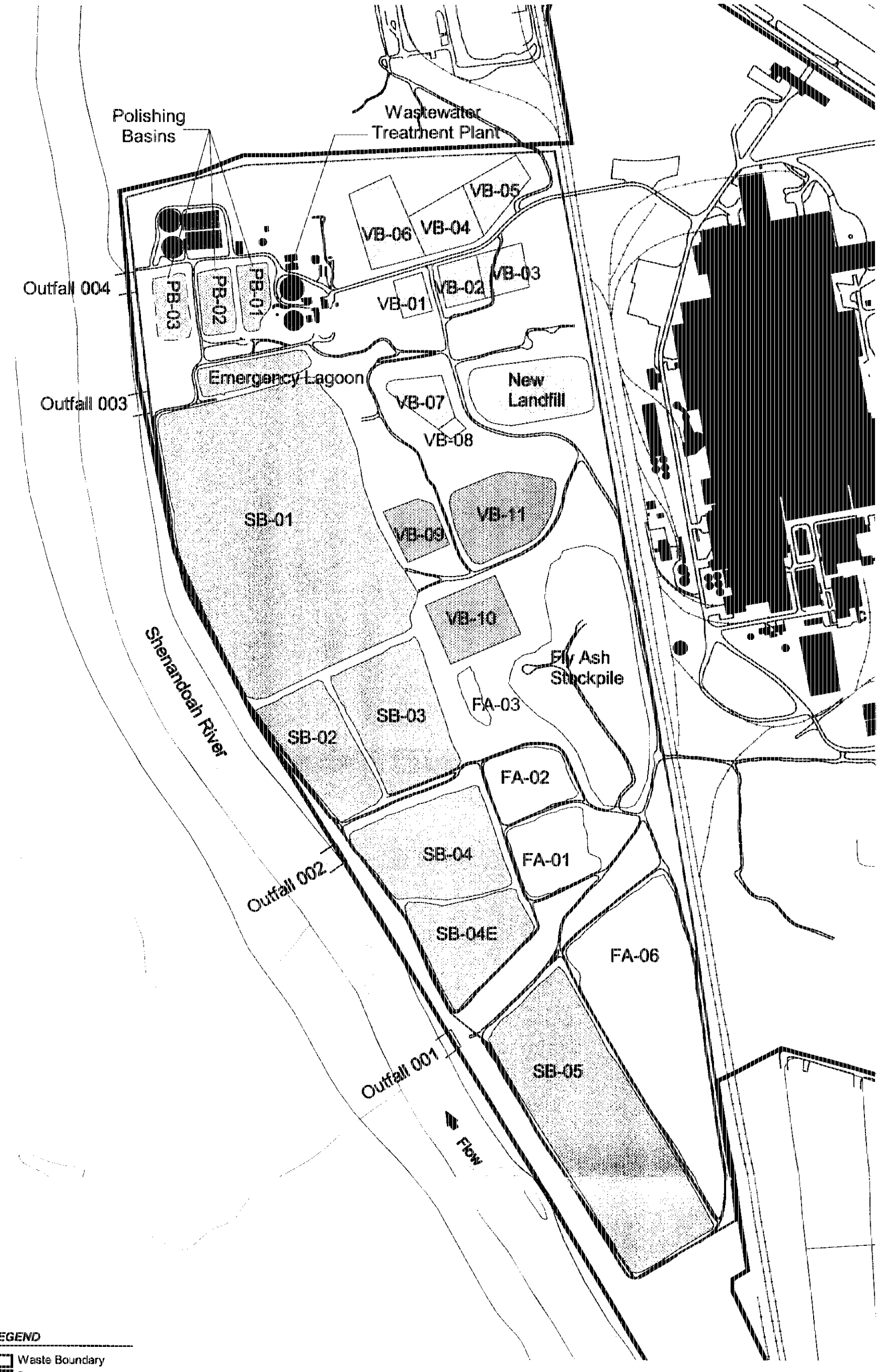

Figure 2-5. Avtex site waste disposal impoundments.

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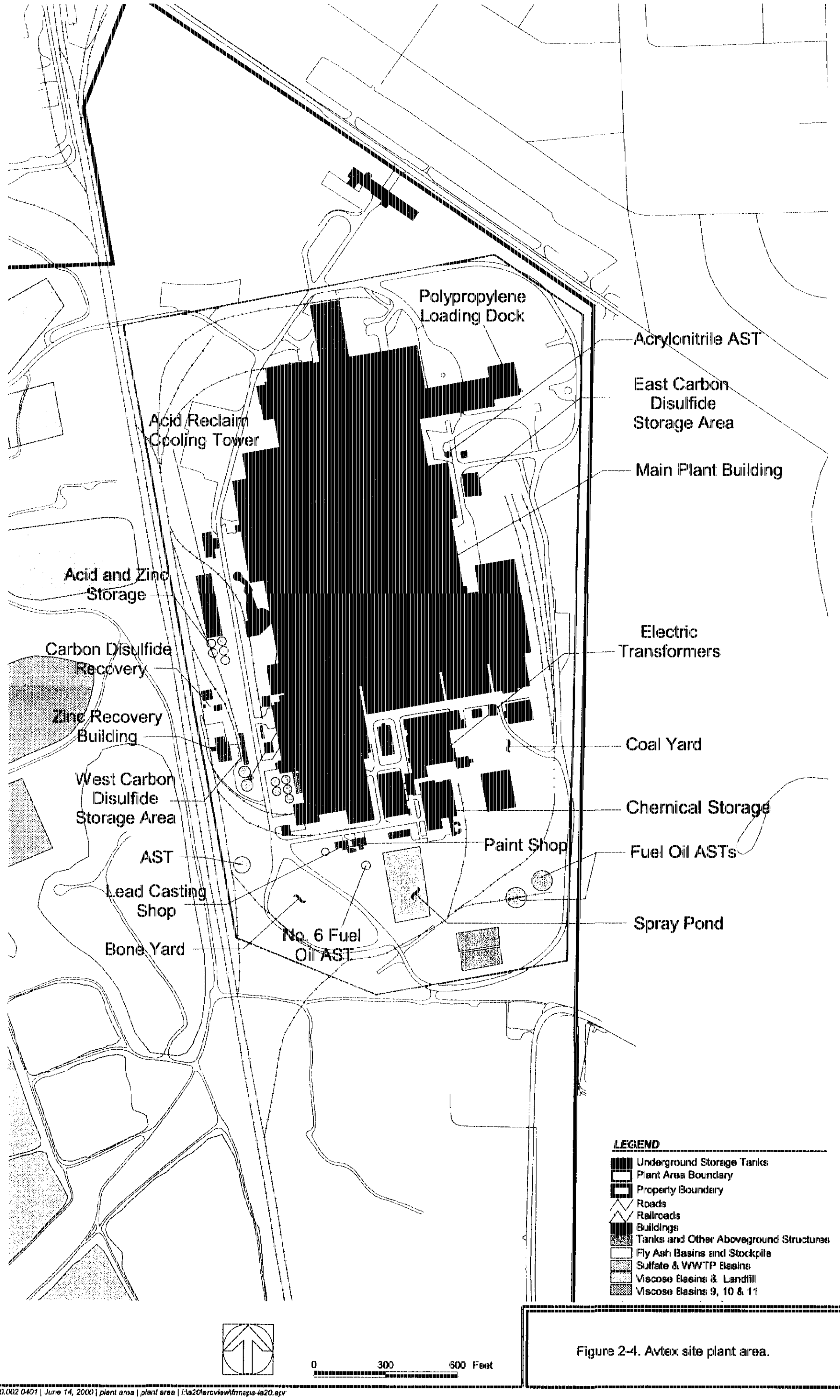

Figure 2-4. Avtex site plant area.

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AR302198

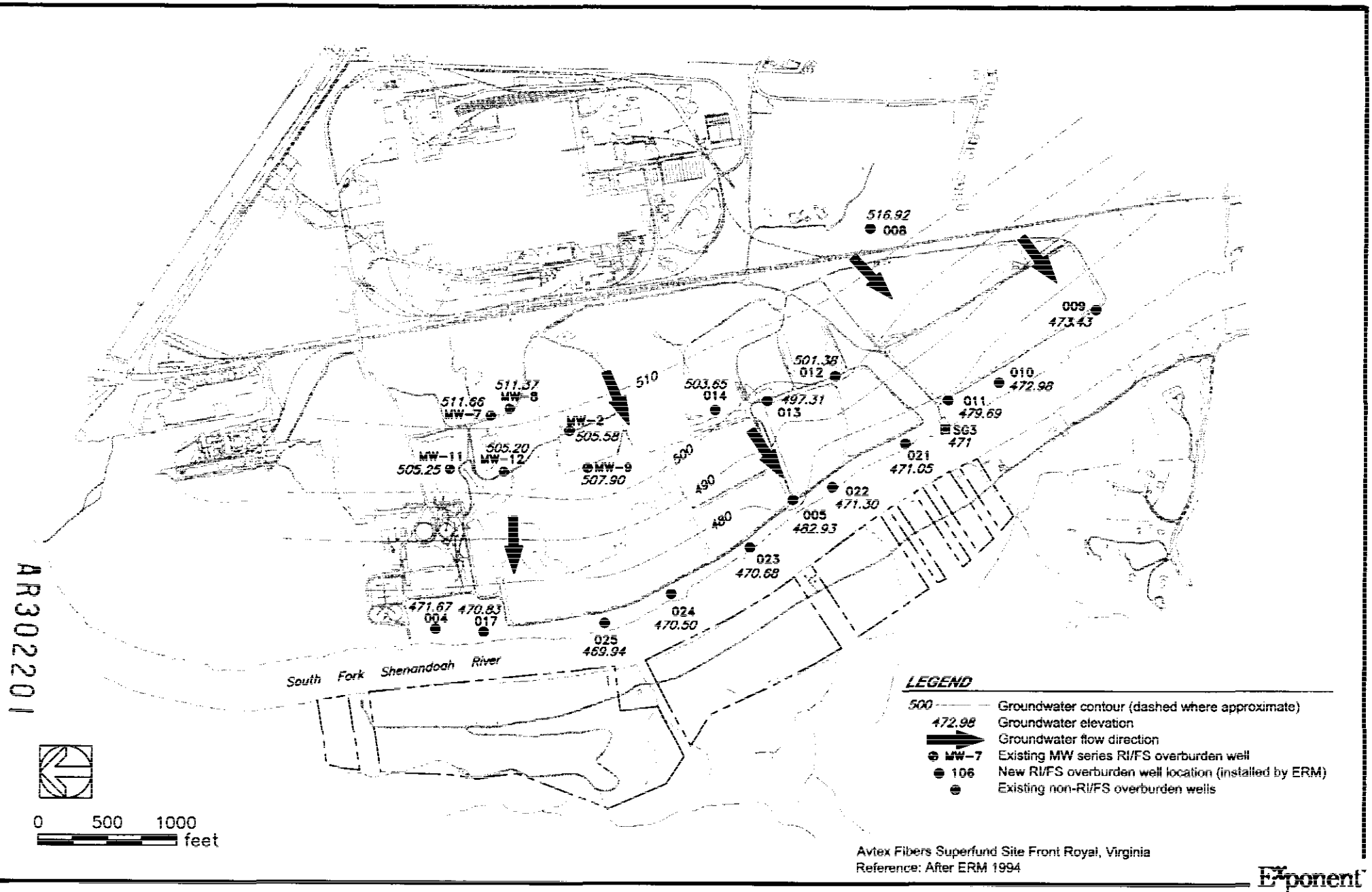
Figure 2-6. Geologic map of the Front Royal area (from Rader and Biggs 1975).

Boulder1\Data\Groups\Graphics\Projects\420\front royal map cdr 06/02/00 CO

Figure 2-7. Avtex site well locations.

8500e20.002 0401 | June 14, 2000 | GW locations | gw locations | I:\a20\arcview\frmaps-ia20.apr

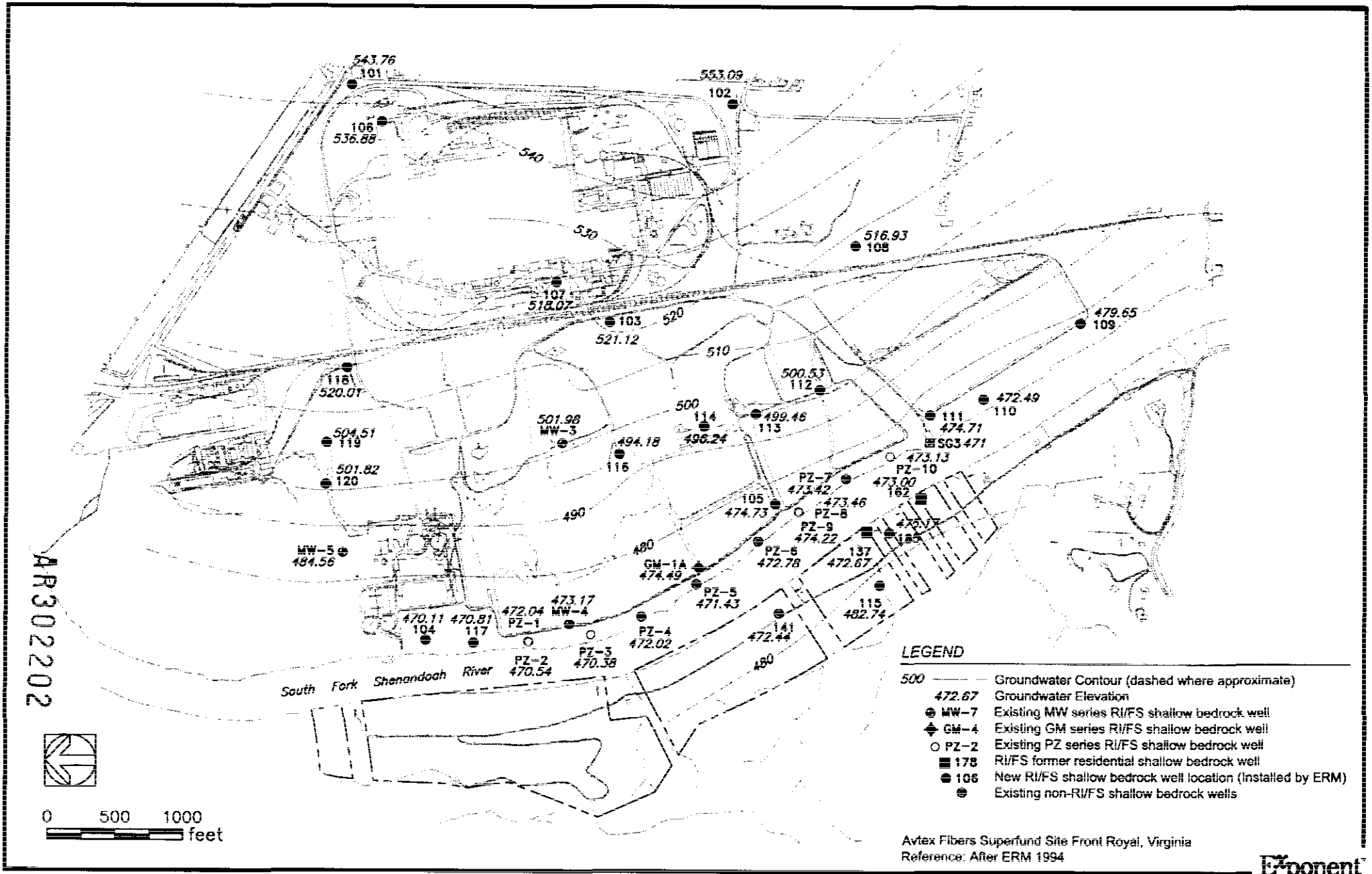
AR302200



AR302201

Figure 2-8. Groundwater potentiometric surface contours for the overburden monitoring wells (4/25/94).

flatirons/cad/ca20/front royal/overburd_cont.dwg 10/18/99 CO



AR302202

Figure 2-9. Groundwater potentiometric surface contours for the shallow bedrock monitoring wells (4/25/94).

flatirons/cad/a20/front royal/sh_bedrock_cont.dwg 10/18/99 CO

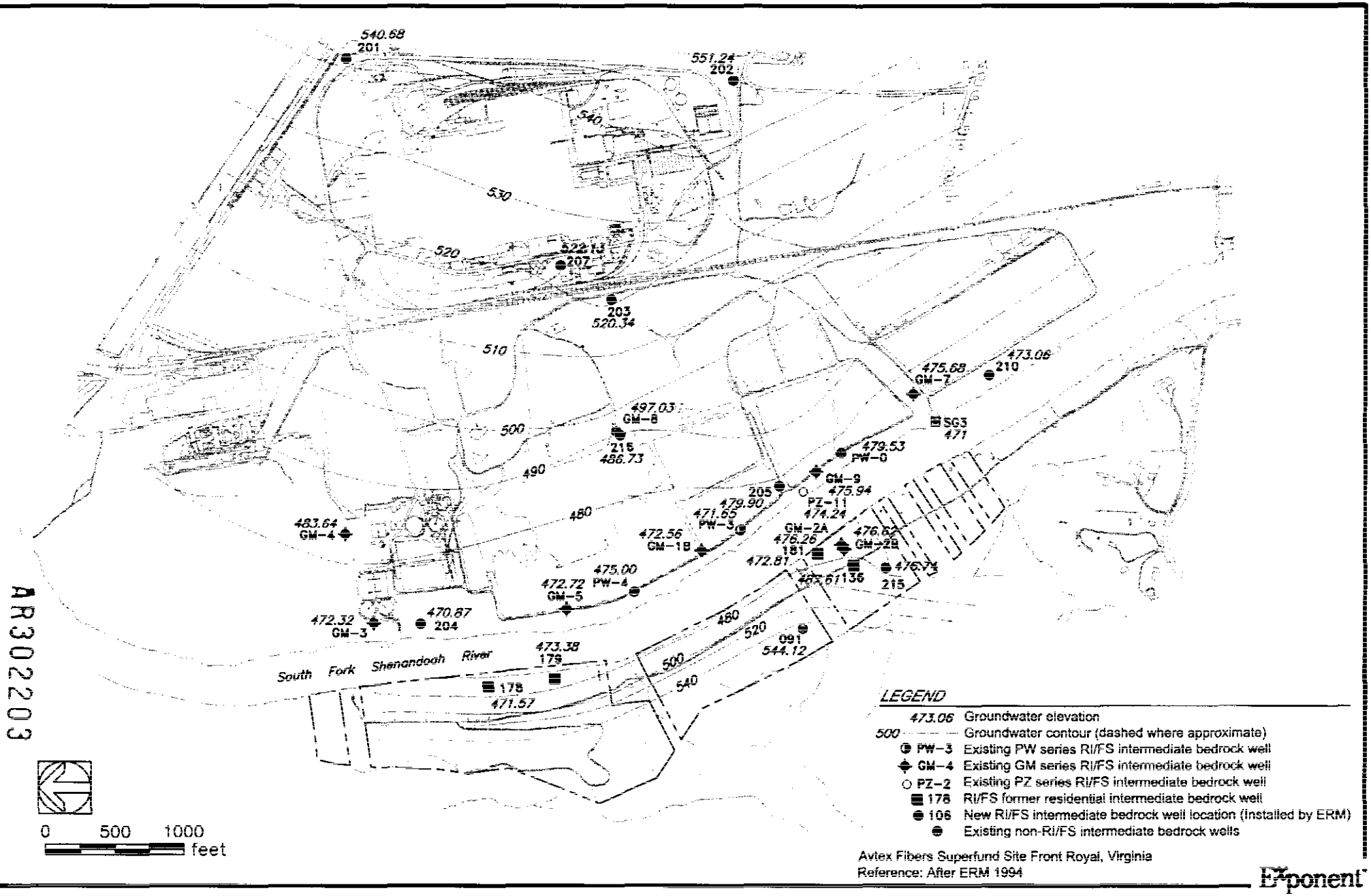


Figure 2-10. Groundwater potentiometric surface contours for the intermediate bedrock monitoring wells (4/25/94).

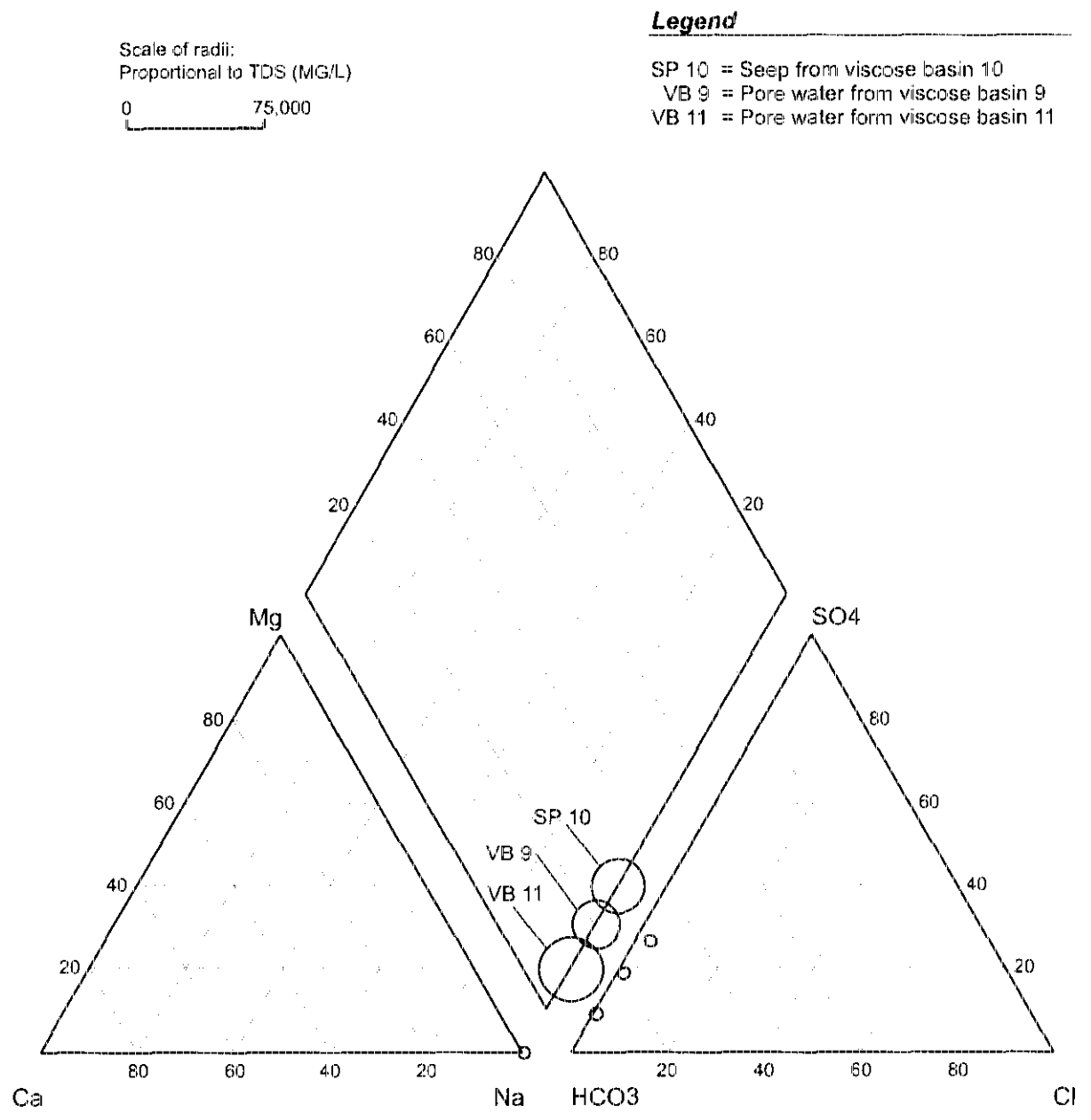


Figure 3-1. Piper diagram depicting the major ion composition of seep and pore water samples from viscose basins 9, 10, and 11.

Boulder1\data\groups\graphics\projects\A20\vb_piper.cdr 08/10/00 CO

Figure 3-2. Distribution of carbon disulfide in groundwater.

Exponent

8600a20.002 0401 | June 14, 2000 | cs2 conc | detect cs2 | R:\a20\anc\env\cs2\detected cs2.apr

AR302205

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DESCRIPTION OF IMAGERY Oversized Maps

NUMBER AND TYPE OF IMAGERY ITEM(S)

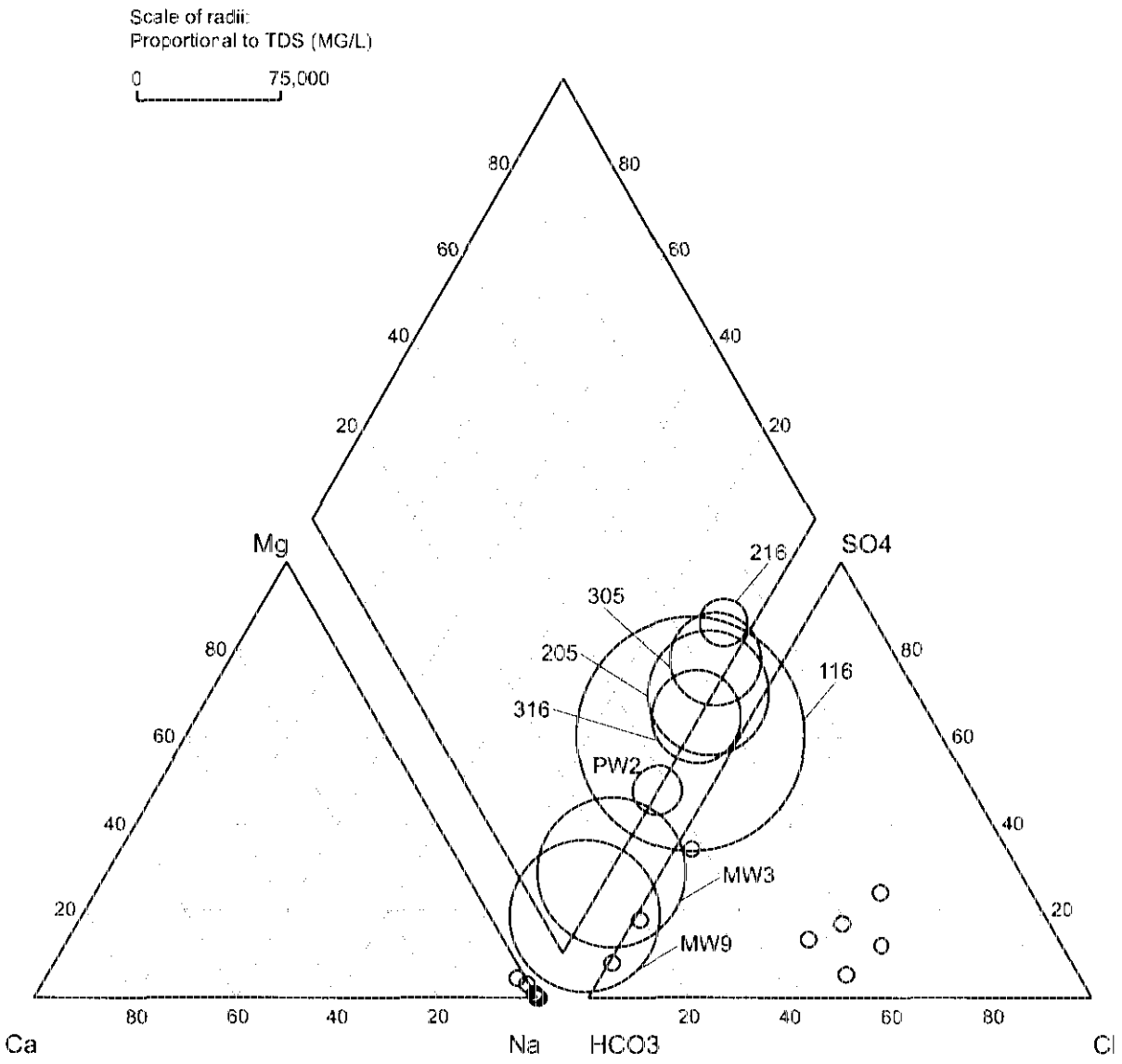

Figure 3-5. Piper diagram depicting the major ion chemistry of groundwater from select wells in the dense carbon disulfide plume.

Boulder1\data\groups\graphics\projects\1192\plume_piper.cdr 06/10/00 CO

AR302208

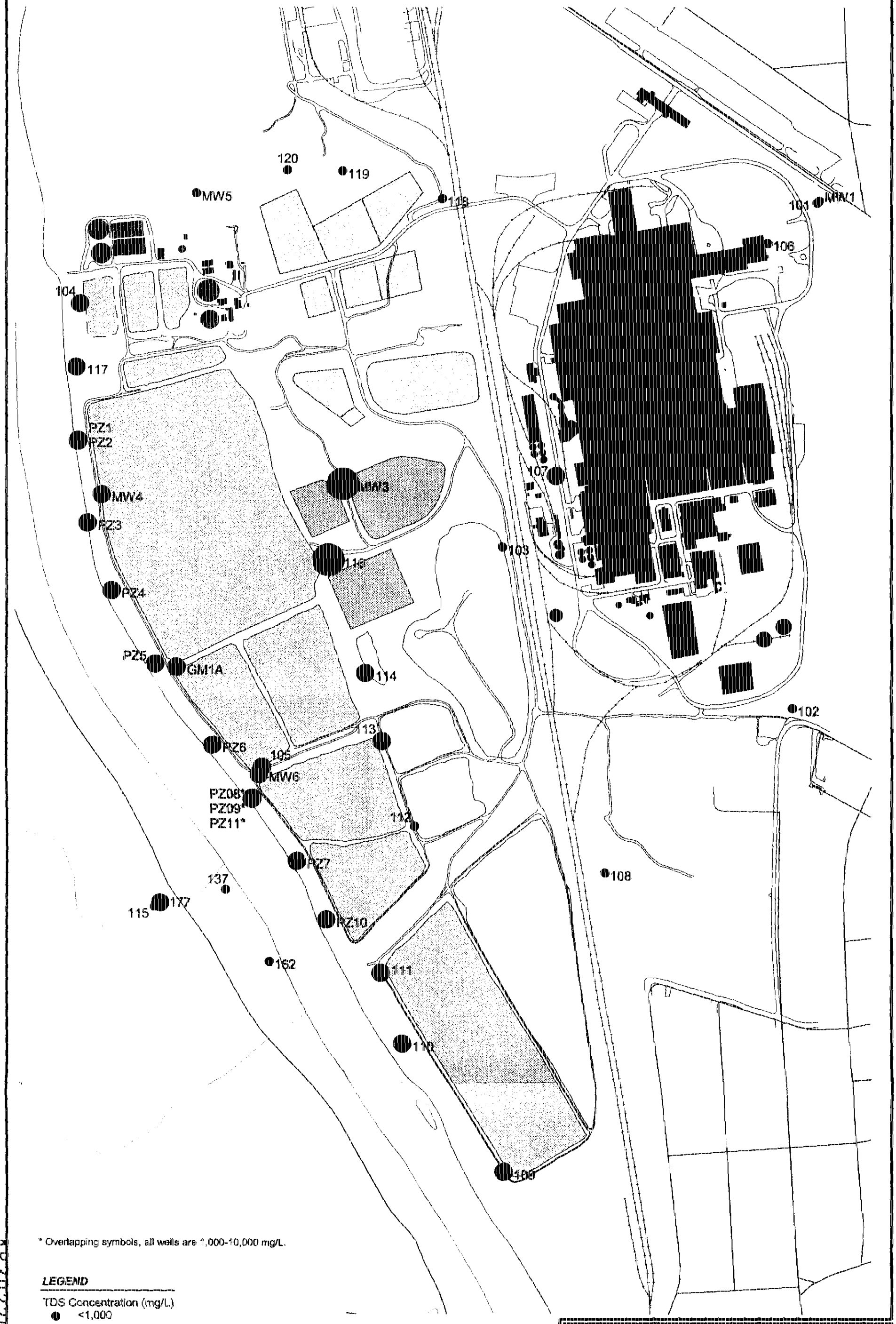

Figure 3-6. TDS concentrations in shallow bedrock groundwater.

8600s20.002 | June 14, 2000 | shallow_tds | shallow_tds | I:\a20\arcview\tds\tds maps.apr

ARS02209

EPA REGION III
SUPERFUND DOCUMENT MANAGEMENT SYSTEM

DOC ID # 464550
PAGE # 302210

IMAGERY COVER SHEET
UNSCANNABLE ITEM

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OPERABLE UNIT 10

SECTION/BOX/FOLDER 34

REPORT OR DOCUMENT TITLE Feasibility Study Work Plan

DATE OF DOCUMENT Aug 6, 2000

DESCRIPTION OF IMAGERY Overall map

NUMBER AND TYPE OF IMAGERY ITEM(S)

Figure 3-7. TDS concentrations in intermediate bedrock groundwater.

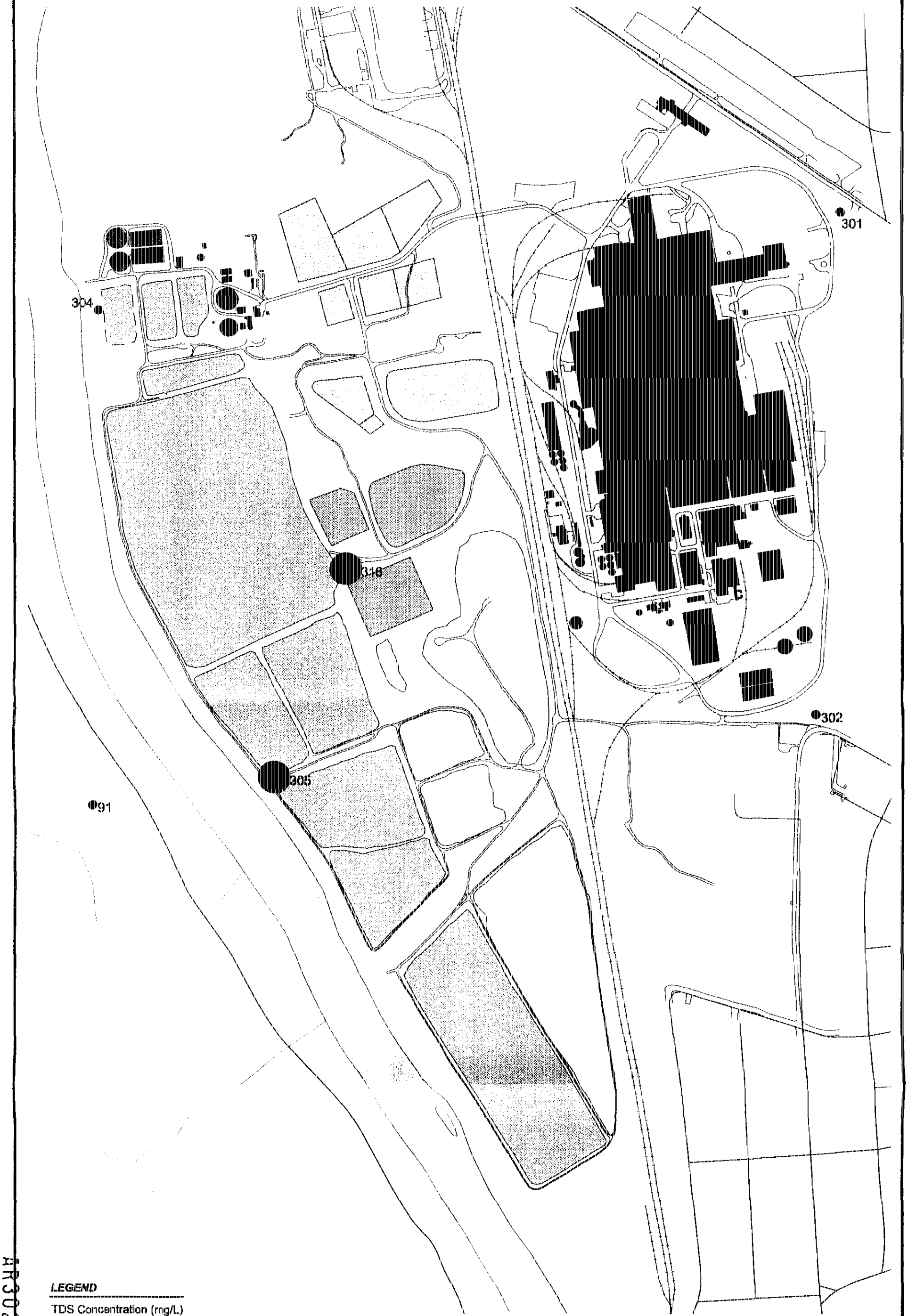


Figure 3-8. TDS concentrations in deep bedrock groundwater.

AR302212

9600a20.002 | June 14, 2000 | deep_tds | deep_tds | I:\a20\ancview\tds\tds maps.apr

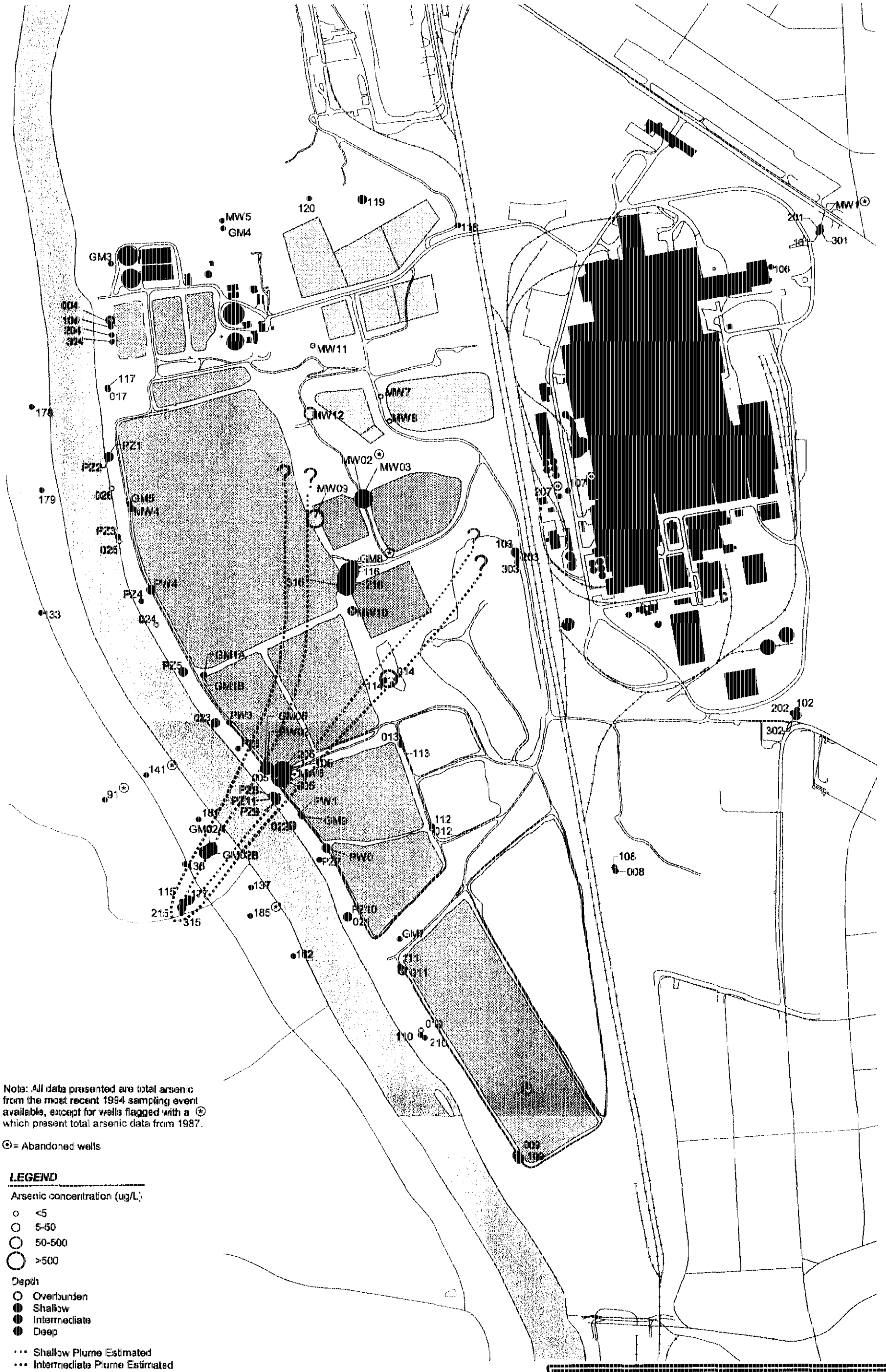
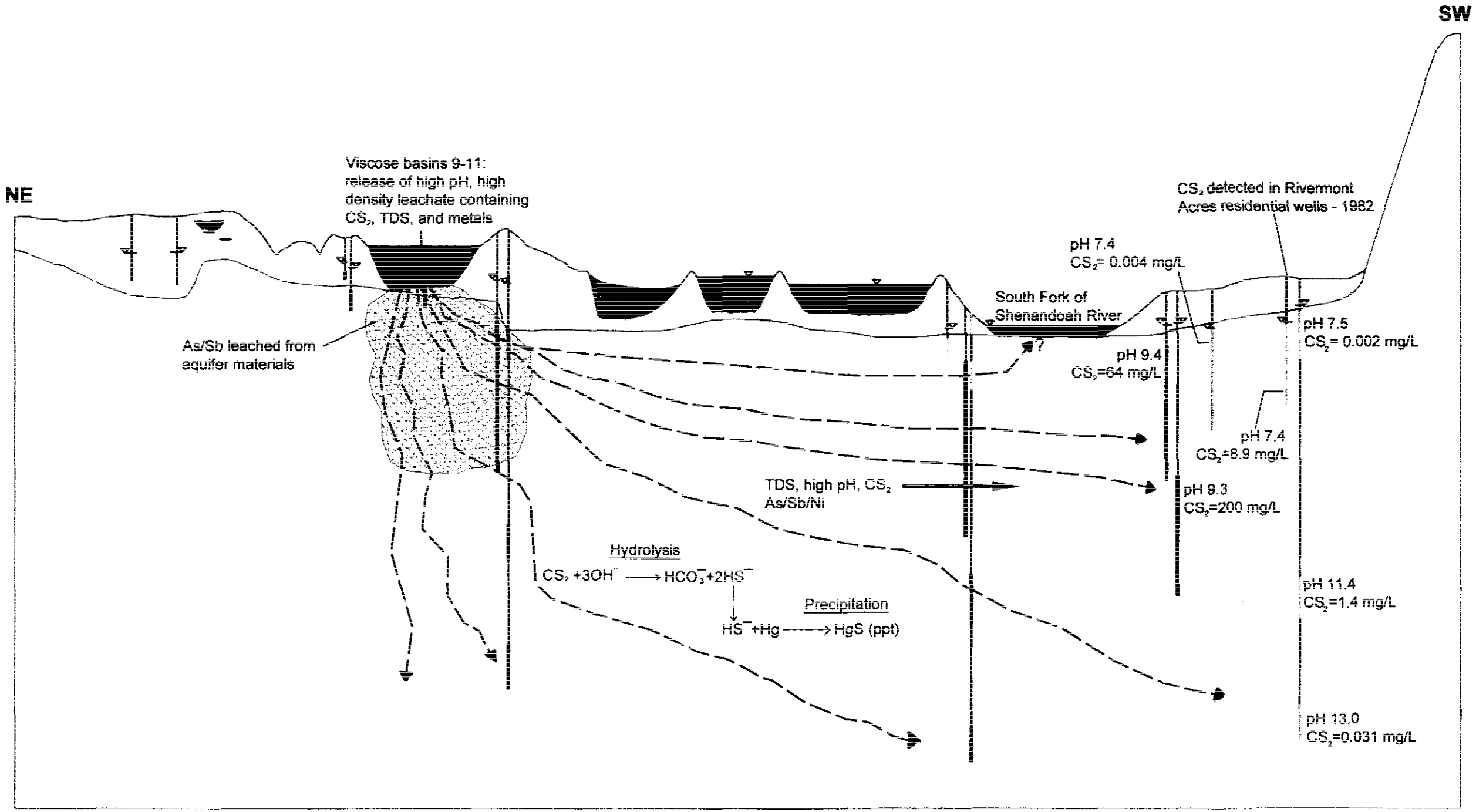


Figure 3-9. Distribution of arsenic in groundwater.

ARS0022173



Note: Vertical exaggeration is 5 times.

LEGEND

- Waste viscose
- Zinc sludge
- Water
- Overburden
- Carbon disulfide concentration > 100 mg/L
- Carbon disulfide concentration 10 mg/L-100 mg/L
- Carbon disulfide concentration 1.0 mg/L-10 mg/L
- Carbon disulfide concentration < 1.0 mg/L
- Generalized transport paths for the dense carbon disulfide plume

0 150 300 feet

Figure 3-10. Fate and transport elements of the Avtex site conceptual model.

\\flatirons\cad\a20\front royal\shenandoah2.dwg 02/10/00 CO

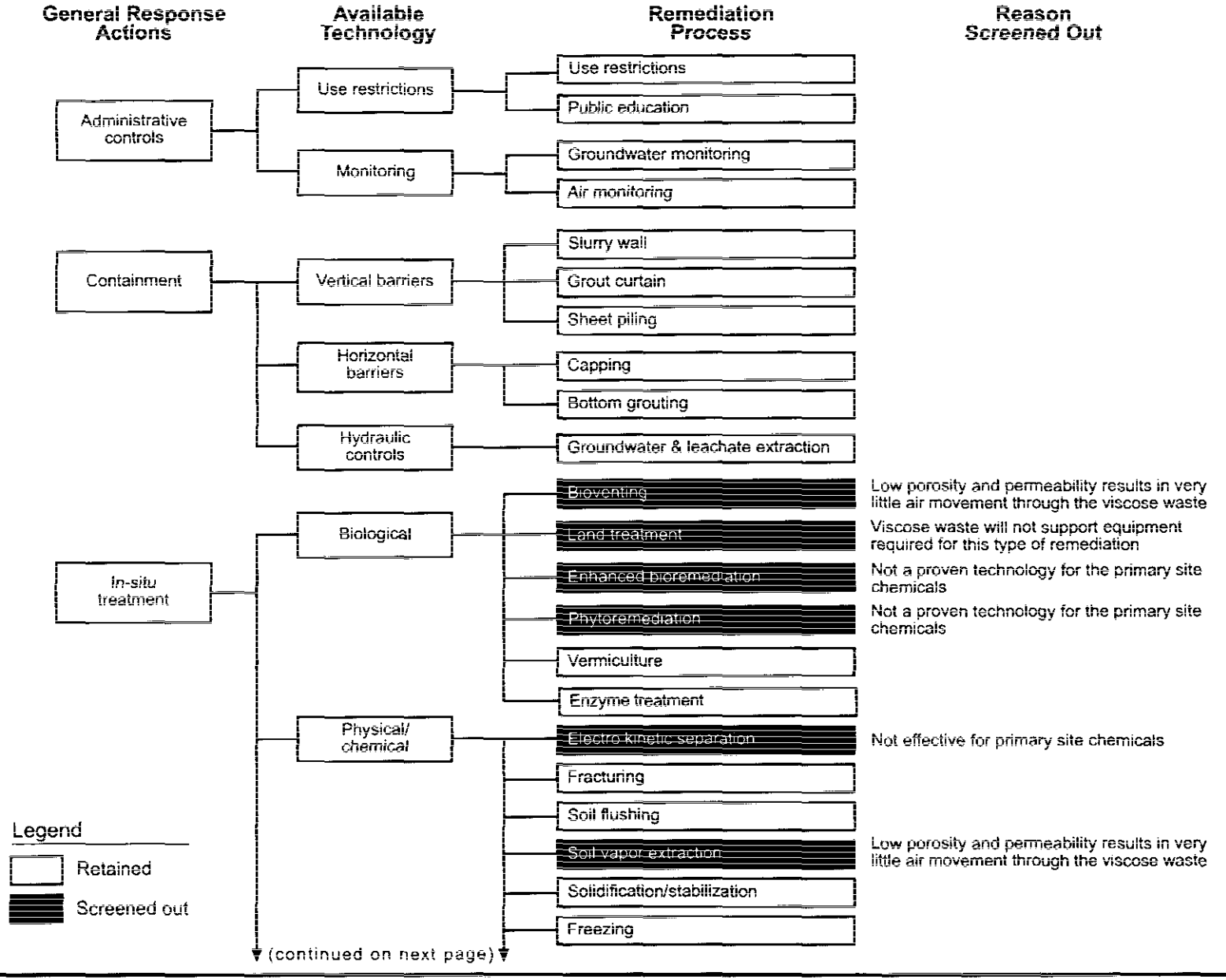


Figure 5-1. Preliminary screening of remedial options for viscose basins 9, 10, and 11.

\\Boulder1\Data\Groups\Graphics\Projects\00A20\remedial options c.fh8 08/10/00 CO

AR302215

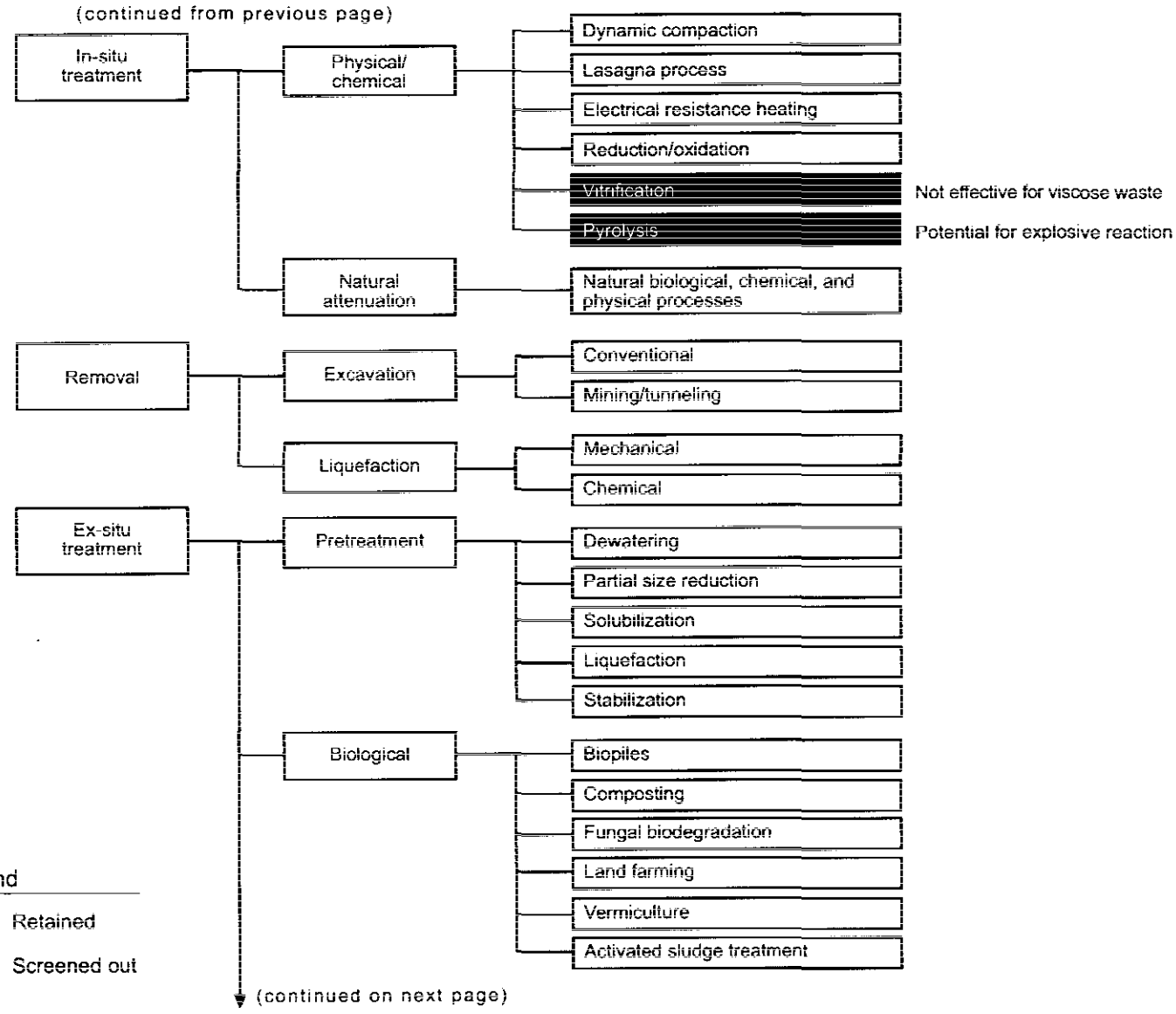


Figure 5-1. (con't.).

AR302216

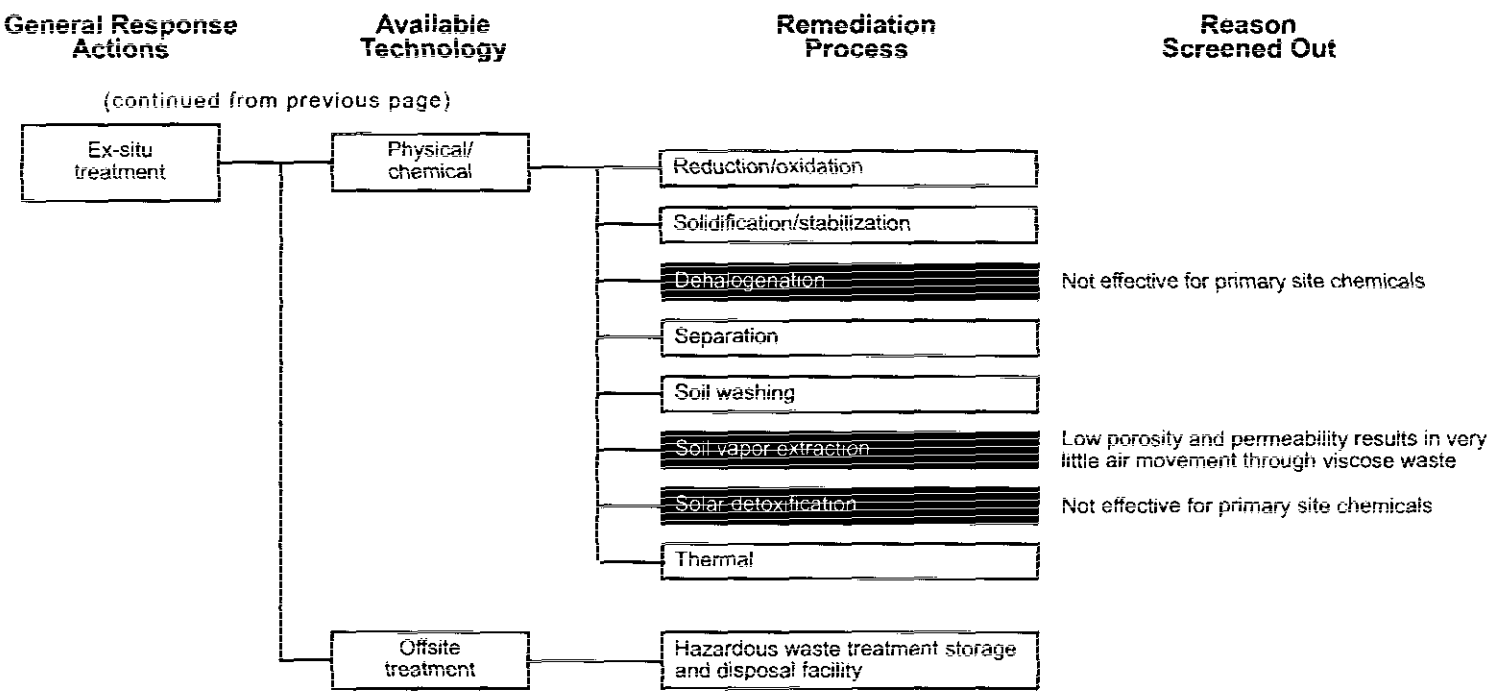


Figure 5-1. (con't.).

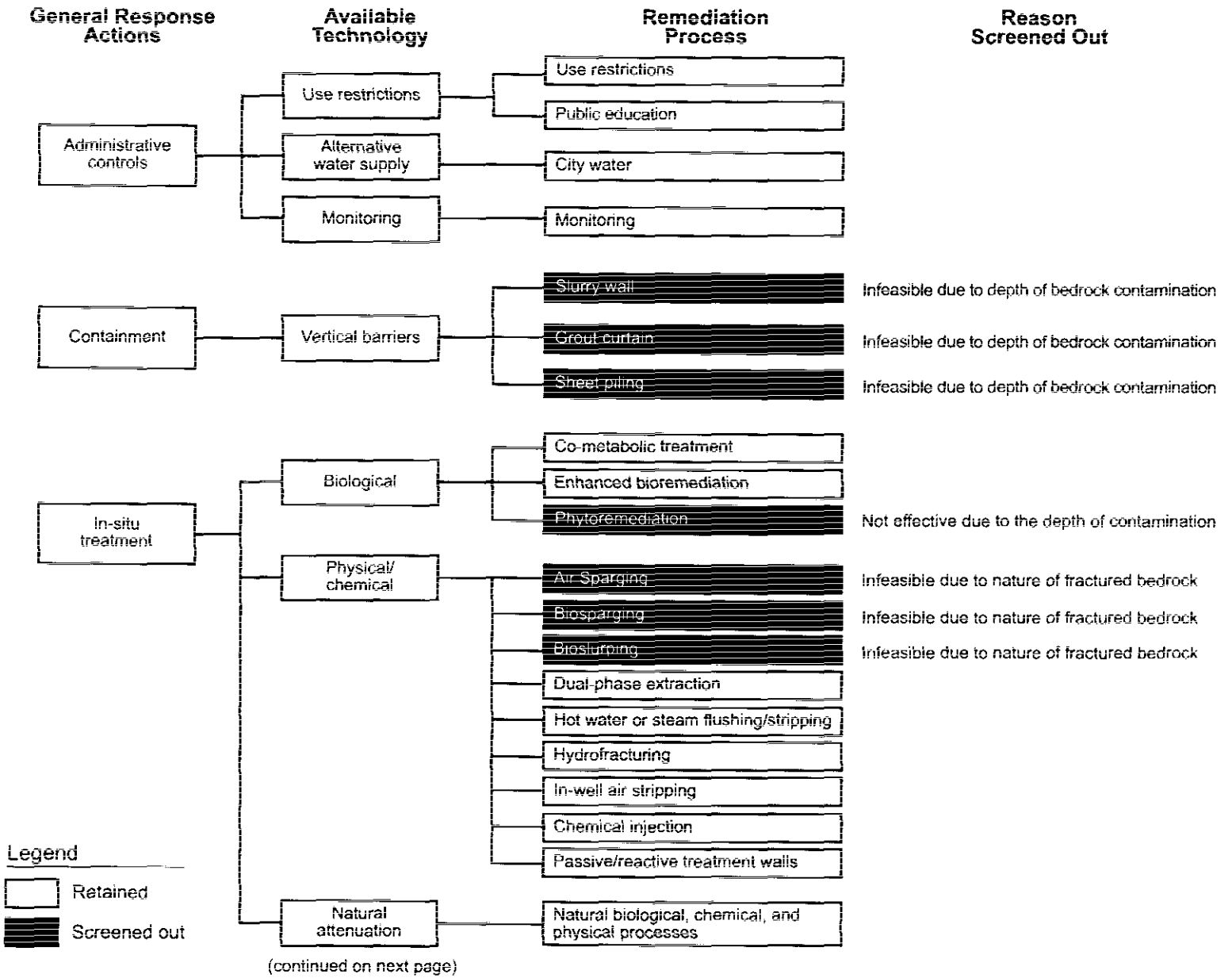


Figure 5-2. Preliminary screening of remedial options for groundwater.

AR302218

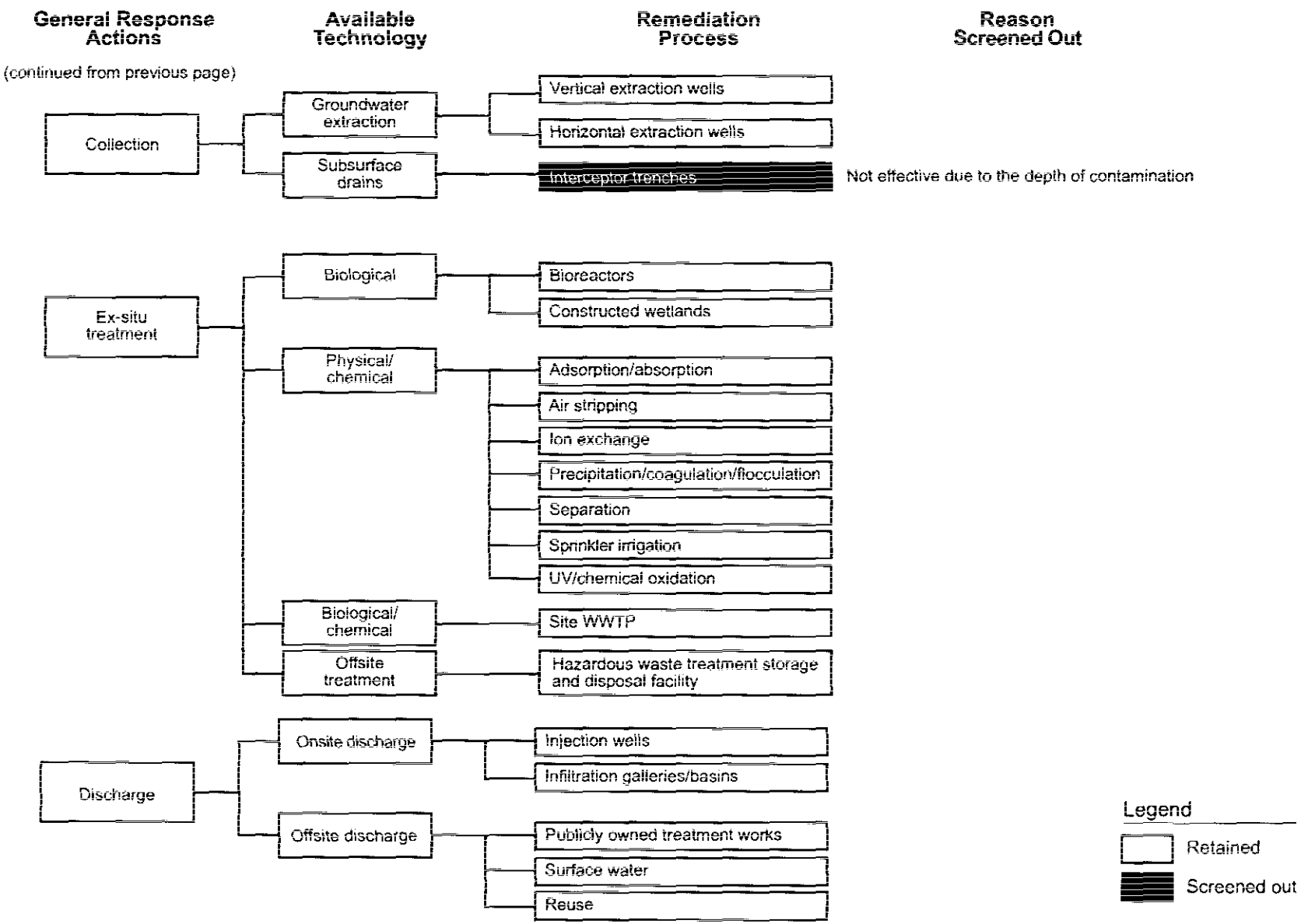


Figure 5-2. (con't.).

AR302219

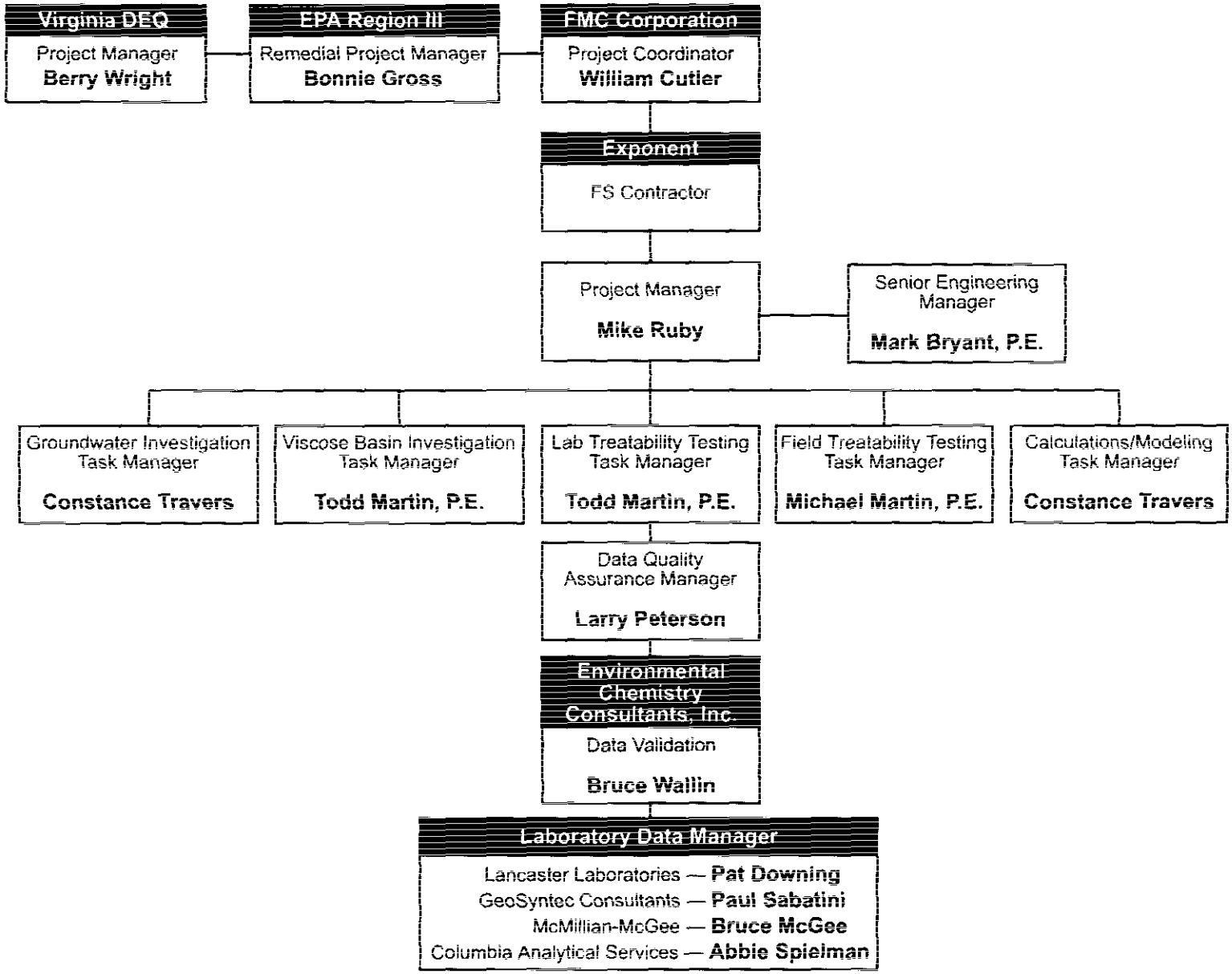
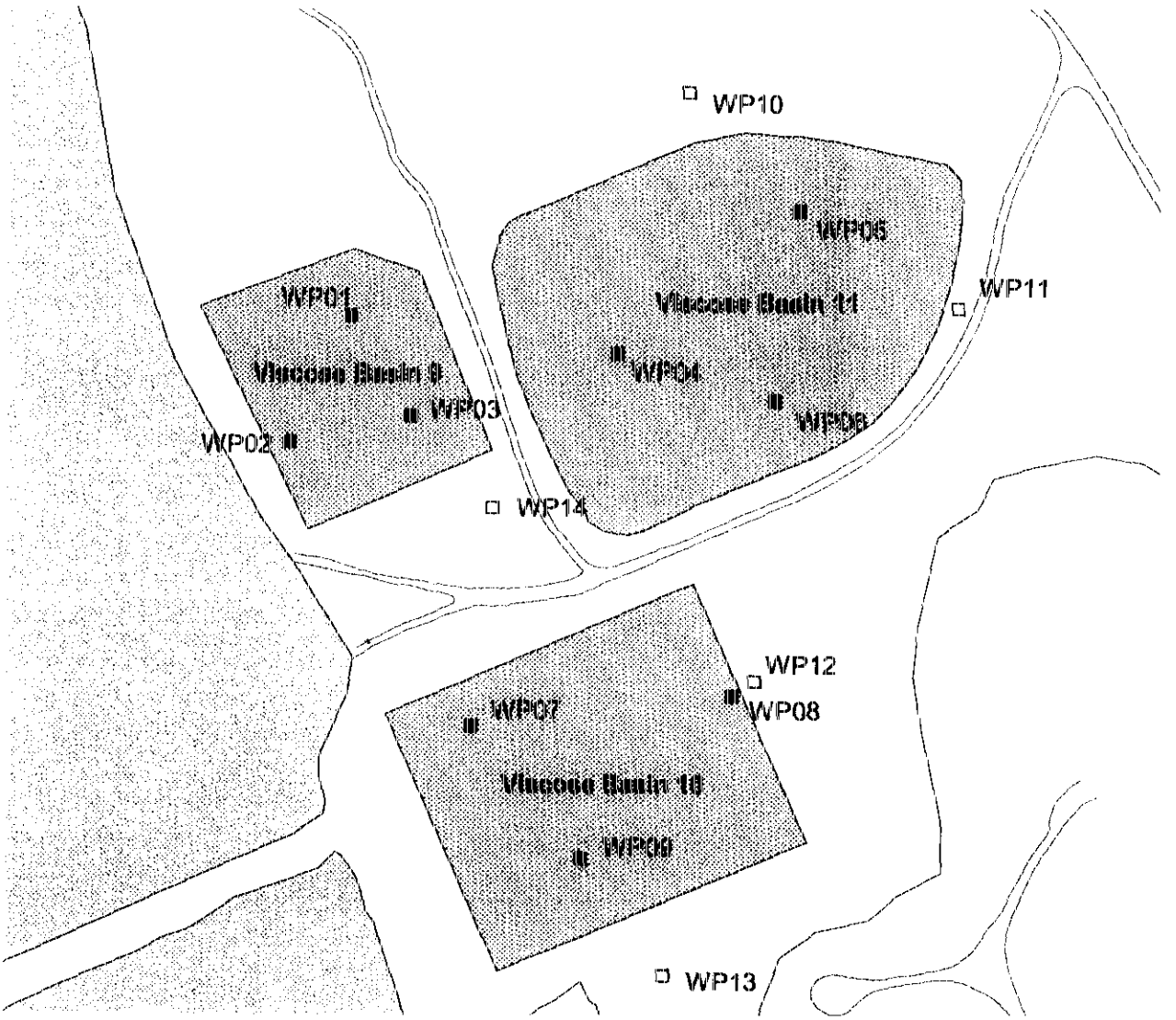


Figure 6-1. Structure of the OU-7 FS project team.

AR302220



LEGEND

- Proposed Location of Viscose Basin Temporary Wellpoint and Borehole Core Sampling
- Proposed Overburden Temporary Wellpoint

0 100 200 Feet

Figure 6-2. Proposed locations for temporary wellpoint installation and borehole core sampling.

8600s20.002 0501 | June 14, 2000 | temporary wells | temporary | i:\s20\arcview\proposed wells.apr

* Overlapping symbols. All are shallow bedrock wells.
** To be installed during Phase II, if necessary.

LEGEND

- Proposed Overburden Geoprobe Sampling Location (GP01 - GP14)
- Proposed Overburden Well
- Proposed Shallow Bedrock Well
- Proposed Deep Bedrock Well
- Overburden Well
- Shallow Bedrock Well
- Intermediate Bedrock Well
- Deep Bedrock Well

0 500 1000 Feet

Figure 6-3. Locations of existing and proposed groundwater monitoring wells and Geoprobe sampling locations.

8600a20.002 0501 | June 14, 2000 | Proposed & existing wells | Proposed wells | E:\a20\revised maps\proposed wells.apr

AR002277

Figure 6-4. Analyses in existing and proposed overburden wells and proposed Geoprobe sampling locations.

8600s20.002 0501 | July 31, 2000 | Proposed analysis/I overburden | overburden | I:\gi\20\revised maps\proposed wells.apr

AR302223

Figure 6-5. Analyses in existing and proposed shallow bedrock wells.

AR302224

8800a20.002 0501 | July 31, 2000 | proposed analysis\sll shallow | shallow | f:\a20\revised maps\proposed wells.apr

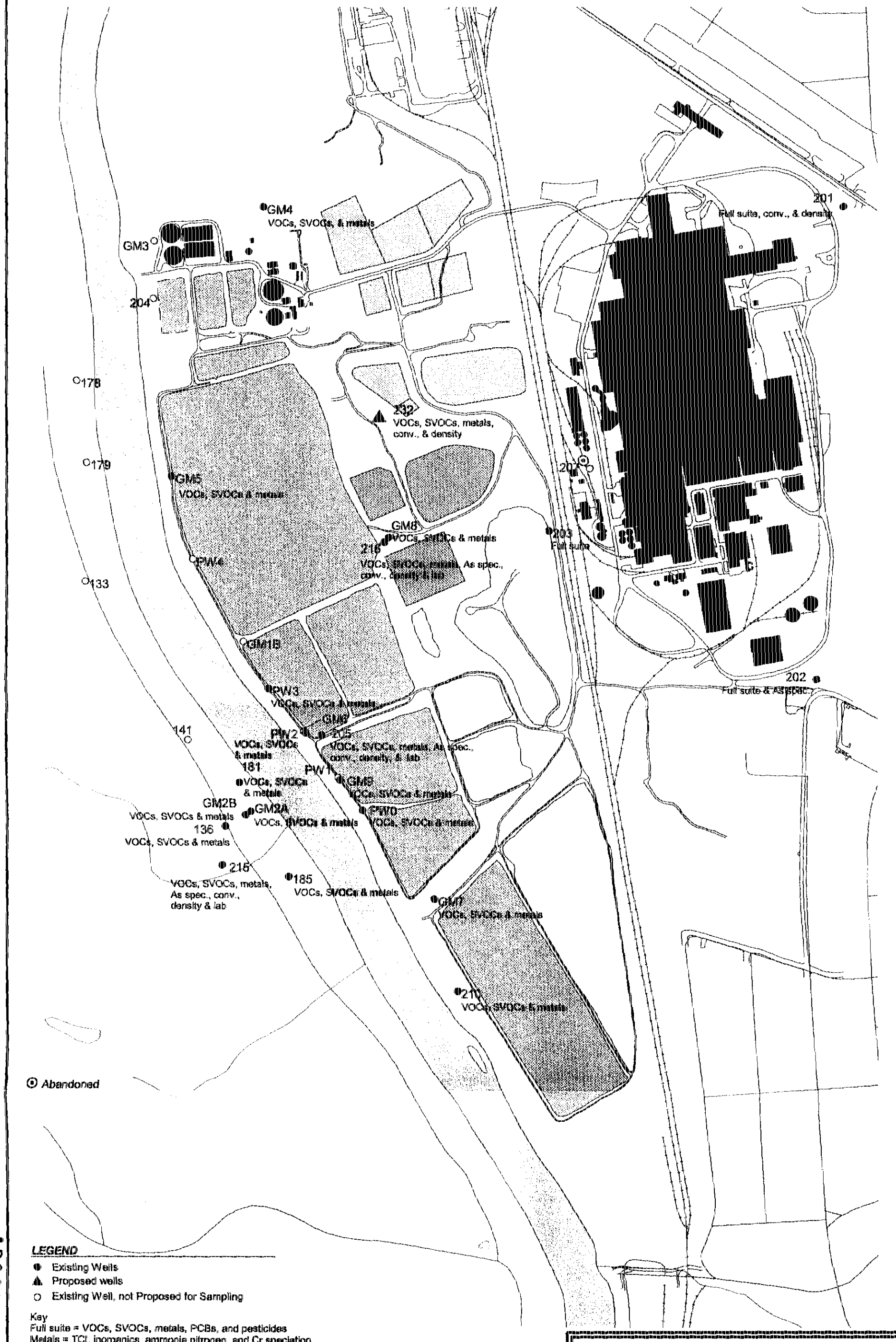


Figure 6-6. Analyses in existing and proposed intermediate bedrock wells.

8600s20.002 0501 | July 31, 2000 | proposed analytes/ intermediate | intermediate | I:\s20\revised maps\proposed wells.apr

AR302776

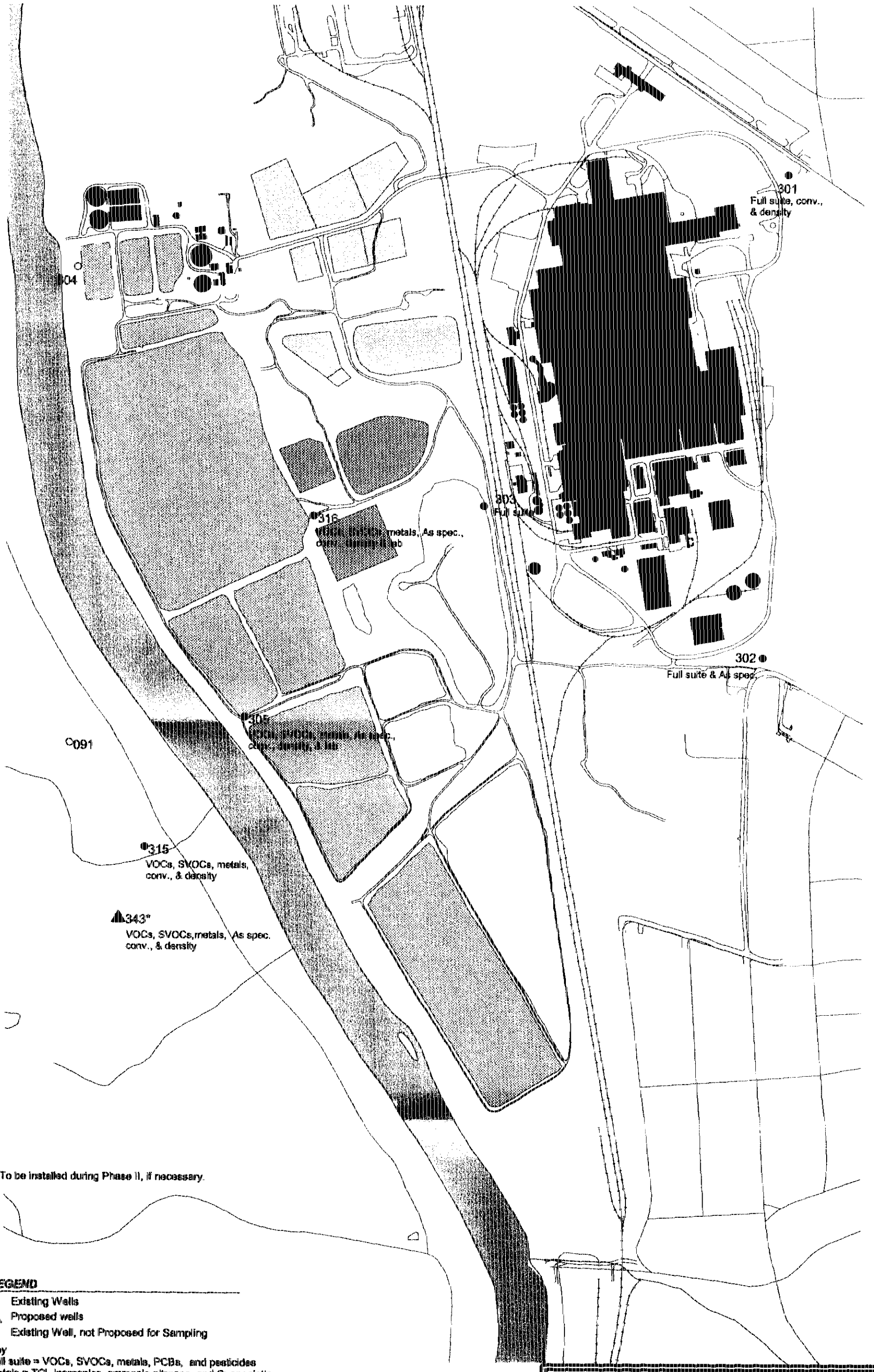


Figure 6-7. Analyses in existing and proposed deep bedrock wells.

8930s20.002 0501 | July 31, 2000 | proposed analysis/f deep | Deep | f:\s20\revised maps\proposed wells.apr

AR302226

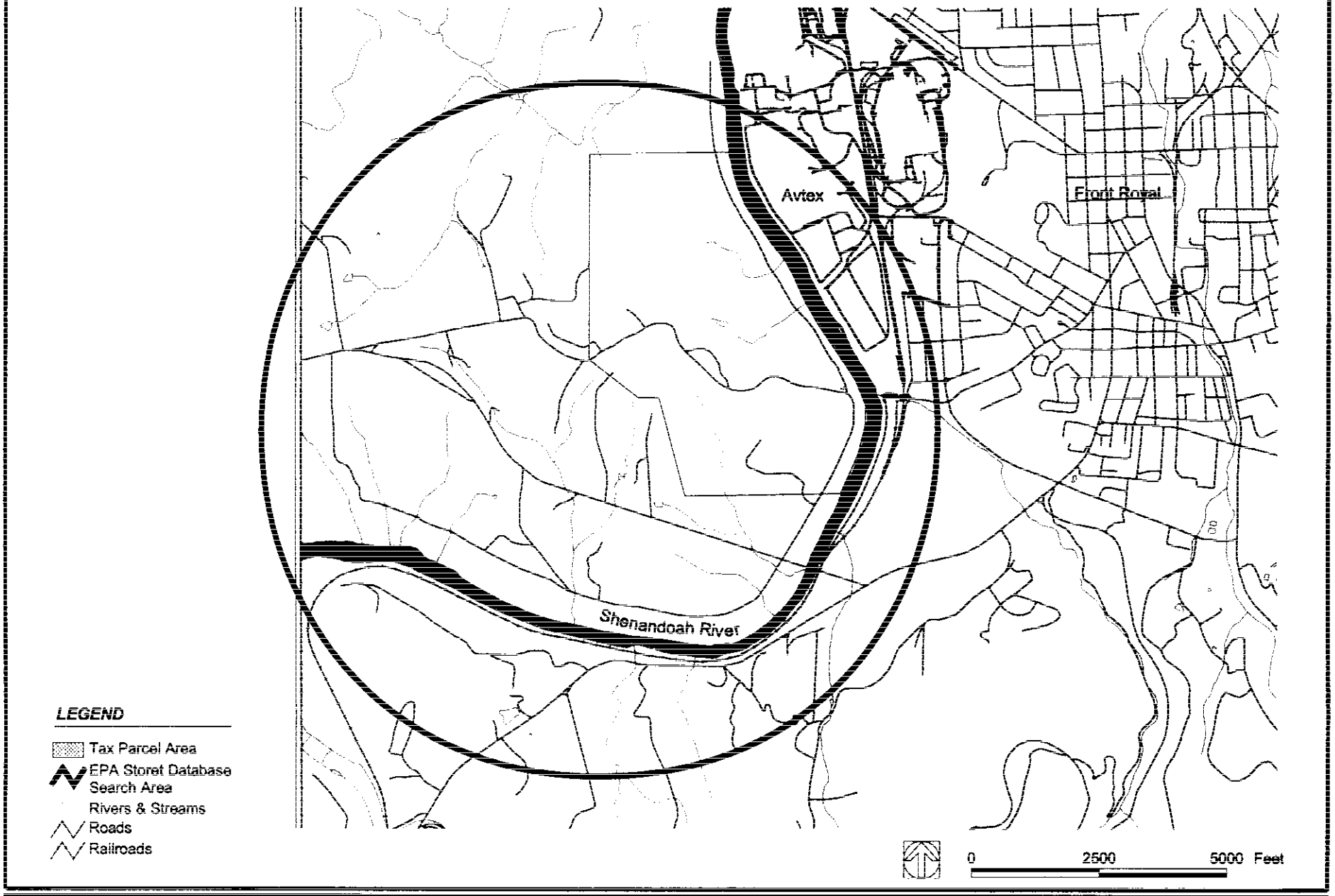


Figure 6-8. Areas for domestic well survey.

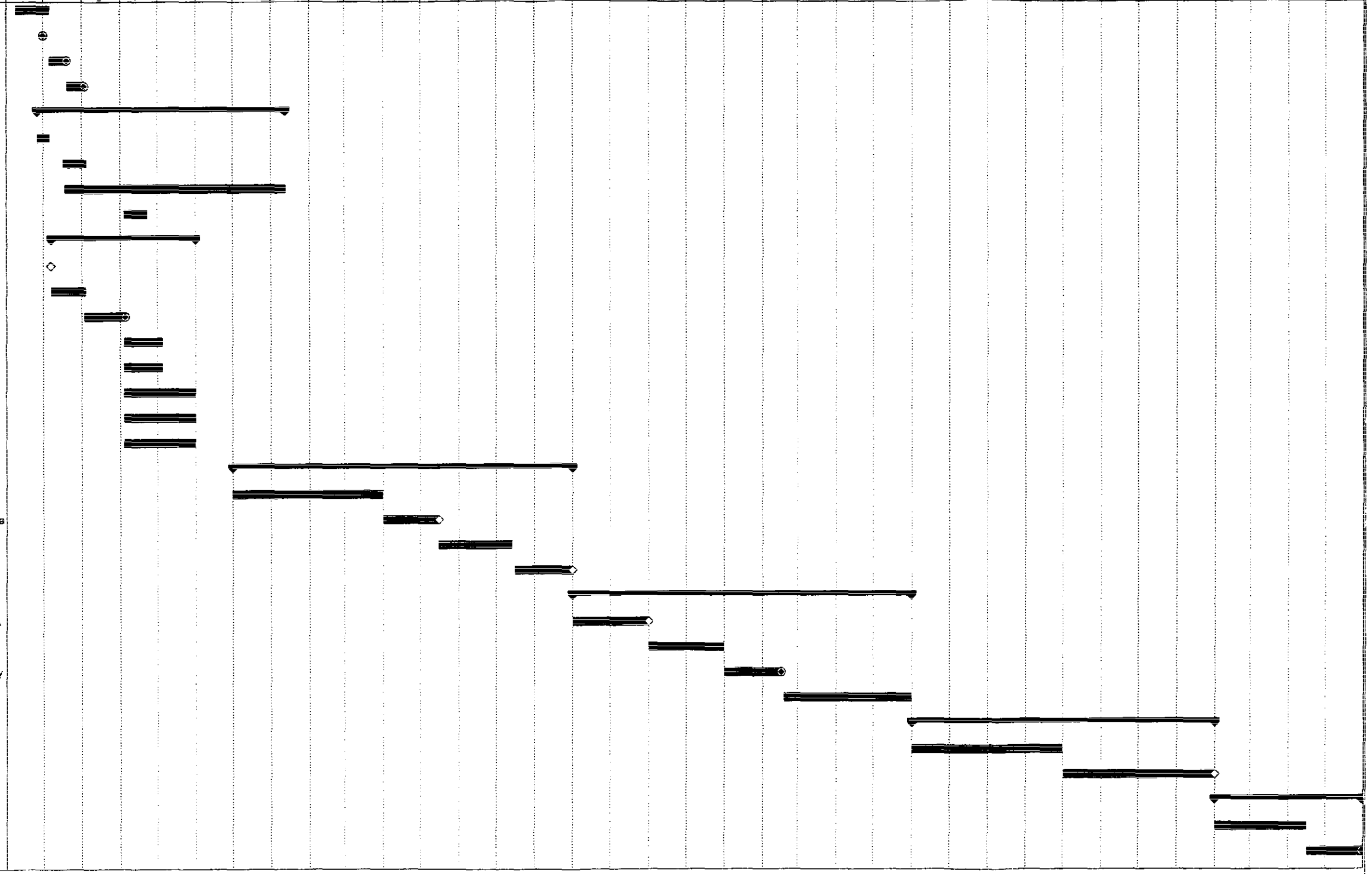
8600a20.002 0601 | Jun 14,2000 | View1 | dom well survey | I:\a20\arcview\domestic well survey.apr

AR302226A

Figure 6-9. Feasibility Study Project Schedule
Operable Unit 7, Avtex Site

Document

ID	Task Name
1	EPA Review of Draft Final FS Work Plan
2	EPA Approval to Proposed Groundwater Sampling
3	Respond to EPA Comments
4	EPA Review & Approval of Final FS Work Plan
5	**Supplemental Field Investigations**
6	Phase I Well Installation
7	Phase I Geoprobe Wellpoint Installation & Groundwater Sampling
8	Carbon Disulfide Hydrolysis Tests
9	Phase II: Infiltrometer & Pump Testing, Water Levels, Viscose Basin Wellpoint Installation & Sampling
10	**Laboratory Treatability Studies**
11	Laboratory Treatability & Analysis Plan Delivered to EPA
12	EPA Review of Laboratory Treatability & Analysis Plan
13	Respond to EPA Comments & Approval of Laboratory Treatability & Analysis Plan
14	Waste Viscose Hydroxide Liberation Tests
15	Waste Viscose Chemical Oxidation Tests
16	Waste Viscose Vermiculture Tests
17	Waste Viscose Direct Electrical Resistance Heating Tests
18	Testing of Techniques for Improving Waste Viscose Handling
19	**Supplemental Field and Laboratory Investigation Data Summary Report**
20	Data Evaluation, Calculations, & Modeling
21	Prepare Supplemental Field & Laboratory Investigation Data Summary Report & Deliver to EPA
22	EPA Review of Supplemental Field & Laboratory Investigation Data Summary Report
23	Respond to EPA Comments & Deliver Final Report to EPA
24	**Field Treatability Studies**
25	Develop Field Treatability & Analysis Plan & Deliver to EPA
26	EPA Review of Field Treatability & Analysis Plan
27	Respond to EPA Comments & Approval of Field Treatability & Analysis Plan
28	Conduct Field Treatability Studies
29	**Prepare Draft OU-7 FS**
30	Data Evaluation, Calculations, & Modeling
31	Prepare Draft OU-7 FS & Deliver to EPA
32	**Finalize OU-7 FS**
33	EPA Review of Draft FS
34	Respond to EPA Comments & Approval of OU-7 FS



Project: 8600A20.002
Date: Wed 6/14/00

Task Duration | Subtask Duration | Milestone | Deliverable

AR302227

Tables

AR302228

Table 2-1. Summary of the regulatory and environmental history of the Avtex site[a]

Date	Activity
1940	American Viscose Corporation begins rayon manufacturing at the site.
1948	The Virginia State Water Control Board (SWCB) issues a directive to American Viscose to install water pollution control devices at the Site.
1963	FMC Corporation purchases the site.
1976	Avtex Fibers purchases the site. A NPDES permit issued to Avtex Fibers specifies effluent limitations and monitoring requirements for WWTP discharges to the Shenandoah River.
1979	To gain compliance with the NPDES requirements, Avtex and the SWCB enter into a Consent Order specifying the addition of acid and alkaline neutralization facilities for the WWTP.
1982	Carbon disulfide is found in residential wells in Rivermont Acres across the river from the plant.
1983	Land disposal of waste viscose is discontinued. The viscose waste stream is directed to the WWTP for treatment.
1983–1984	Avtex initiates interim remedial measures, including purchase of 23 residential properties in Rivermont Acres with domestic wells affected by groundwater contamination, and initiates groundwater counter-pumping, and dewatering of viscose basins 9, 10, and 11.
1984	The site is proposed for inclusion on the National Priorities List (NPL).
1986	EPA enters into an Administrative Order on Consent directing Avtex Fibers to conduct a Remedial Investigation/Feasibility Study (RI/FS) to evaluate the magnitude and extent of groundwater contamination resulting from the disposal of waste viscose at the Site. The Site is added to the NPL.
1987	The 1986 RI/FS work plan is approved. RI work begins with the installation of monitoring wells and sampling of groundwater and site waste materials.
1988	January: The 1986 Administrative Order is amended to add FMC as a respondent. August: Interim Final RI submitted to EPA. EPA prepares a Proposed Remedial Action Plan (PRAP) detailing EPA's preferred alternative for groundwater, the Site's first operable unit (OU1). September: EPA issues the Record of Decision (ROD) for OU1 specifying pump-and-treatment of contaminated groundwater and dewatering of viscose basins 9, 10, and 11.
1989	May: Virginia Department of Health issues an advisory against consumption of fish from the Shenandoah River. June: EPA issues an Administrative Order requiring Avtex and FMC to implement the ROD for OU1. July: PCB contamination is discovered at the Site and, as a result, the State of Virginia files a $19.7 million environmental damage suit against Avtex for violating the NPDES permit. September: EPA initiates a removal assessment for PCB-contaminated soils at the Site. October: EPA issues a unilateral Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) 106 Order to Avtex requiring study and removal of PCB contamination, waste identification, segregation and disposal of hazardous substances contained in drums, and a study to determine the potential for release of hazardous substances associated with site processes, operations, and chemical/waste storage. November: As part of ongoing enforcement actions, the state of Virginia revokes Avtex's NPDES permit—forcing Avtex to shut down the WWTP and abandon the Site. EPA receives notice that Avtex is financially unable to carry out its obligations under the June and October 1989 Orders. Under CERCLA, EPA declares an emergency situation due to the uncontrolled nature of the Site resulting from the plant shutdown. EPA begins time critical removal actions. December: EPA issues a Special Notice Letter under CERCLA to both Avtex and FMC to finance or perform an additional RI/FS at the Site.

Table 2-1. (cont.)

Date	Activity
1990–1992	EPA's initial emergency response lasts 2 years and includes maintenance of freeboard in the sulfate and WWTP basins by operating the WWTP, stabilization and removal of bulk chemicals, neutralization of process acids, decommissioning of the carbon disulfide tanks and impoundments, consolidation of 3,000 drums, and stabilization of PCB-contaminated soils around the loading docks.
1990	February: EPA issues an Administrative Order requiring FMC to operate the WWTP and maintain freeboard on the sulfate basins until a remediation alternative is developed. Avtex files for bankruptcy.
	April: FMC assumes operation of the WWTP and upgrades the plant to improve treatment efficiency.
	September: EPA issues the ROD for OU2---soil contamination, waste storage, acid reclamation activities, and site security and safety.
	December: EPA terminates negotiations with FMC regarding performance of an RI/FS.
1991	September: Decommissioning of the carbon disulfide tank farm is completed under an EPA removal action.
	March: EPA initiates removal of PCB-contaminated soil and debris.
1992	April: Dismantling/demolition of acid reclaim facility complete.
1993	February: Under EPA direction, Halliburton/Gannett Fleming complete RI/FS work plan for the site.
	April: FMC enters into an Administrative Order of Consent with EPA to perform the RI/FS.
1993–1994	RI field investigation. RI Summary report issued in December 1994.
1999	February: EPA completes the final ecological risk assessment for the site and the adjacent reach of the South Fork of the Shenandoah River.
	May: The final engineering evaluation/cost analysis (EE/CA) for remediation of the sulfate basins, WWTP basins, and fly ash basins and pile is completed by FMC.
	August: The baseline human health risk assessment for the onsite soils, sulfate basins, wastewater treatment plant basins, viscose basins, and the fly ash basins and pile is completed by FMC.

[a] Information prior to 1993 from Halliburton/Gannett Fleming (1993). Post-1993 information from EPA (2000).

Table 2-2. Description of plant-area facilities

Plant Area	Description
Main Building	The main building was constructed in 1937 and contained 150 major rooms. Because the building housed the entire rayon manufacturing process, many chemicals and intermediate products were present. In addition, 50 spill areas were identified by the EPA within the plant area. Demolition and clean-up of the main building has begun.
Sewer Systems	The plant area was served by an extensive sewer system that was originally built in the 1940s, but was periodically expanded and upgraded to meet the increasing needs of the facility. The sewer system, which totals more than 10 miles of length and nearly 200 manholes, includes lines for conducting process wastes, sanitary wastes, and stormwater. The stormwater lines makeup nearly half the system and drained directly to the Shenandoah River until 1989 when most of the stormwater was re-directed to sulfate basin 1. The process and sanitary sewers discharged to the WWTP.
East and West Carbon Disulfide Storage Area	Carbon disulfide, used in the viscose process, was stored in aboveground storage tanks (ASTs), which were situated in concrete basins. The basins were flooded with water to completely submerge the ASTs and prevent inadvertent release of carbon disulfide to the atmosphere. The basin water, carbon disulfide, and the ASTs have been removed from the site, and the basin concrete foundations will be removed in the near future.
Aboveground Storage Tanks	Several ASTs are/were present at the site. These tanks stored chemicals such as petroleum fuel, fuel oil, acyrlonitrile, sulfuric acid, and soda. The tanks and their contents have been (or will be) removed as part of the site closure activities.
Underground Storage Tanks	Several underground storage tanks (USTs) were present at the site to store gasoline, sulfuric acid, diesel fuel (two tanks), and fuel oil (two tanks). A seventh UST was present at the Site as part of the carbon disulfide recovery system.
Boneyard	The Boneyard was used to store equipment and various containers for subsequent salvage. These materials, which were removed as part of the site closure activities, may have contained solvents, oils, and metals.
Zinc Recovery Building	In this building, zinc hydroxide taken from the sulfate basins was converted to zinc sulfate for reuse in the rayon manufacturing process.
Lead Casting Shop	Lead was smelted in this building to make parts for rayon production machinery.
Polypropylene Loading Dock	Releases of PCBs occurred at the loading dock; the affected soils have been removed.
Acid Reclaim Building	This building was used for the reclamation of acids from the viscose process.
Paint Shop	Paints and solvents were used and stored in the paint shop.
Chemical Storage Area	Storage area for plant chemicals.
Coal Yard	Area was used to store coal used by the plant power house. A transformer fire occurred on the roof of the adjacent building.
Acid Reclaim Cooling Tower	Cooling tower for the acid reclaim process. Chromium-based chemicals were used for treatment of the cooling water.
Spray Ponds	Treatment of the cooling water using chromium-based chemicals was conducted in this area.

AR302231

Table 2-3. Description of waste-area facilities

Waste Area	Description
Sulfate Basins	Six unlined impoundments located along the banks of the Shenandoah River; that cover a total of 85 acres. These basins received zinc hydroxide sludge generated during the neutralization of acid process waters at the WWTP. Biological sludge generated by the WWTP activated sludge facility was also disposed of in the sulfate basins.
Viscose Basins	Eleven unlined, excavated, and bermed impoundments that received waste viscose produced during rayon manufacture.
Viscose Basins 1 through 8	These eight basins received an estimated 174,000 cubic yards of waste viscose that was end-dumped into the basins.
Viscose Basins 9, 10, and 11	These three basins are the youngest basins and received an estimated 363,000 cubic yards of waste viscose that was pumped as a slurry into the basins.
Fly Ash Basins/Stockpile	There are four fly ash basins and one fly ash stockpile at the site. These facilities were used for disposal of solid particulates collected from the site bag house and boiler house. The basins and stockpile are estimated to contain 698,000 and 592,000 cubic yards of material, respectively. The solids were pumped as a slurry to the basins, where they were allowed to settle. Periodically, solids were dredged from the basins and placed in the stockpile.
Landfill	The landfill was constructed above grade as "valley fill" and has a leachate collection system that conveys leachate to the WWTP. Landfilled material included solidified viscose, off-specification rayon yarn, and plant and construction debris, with a total estimated volume of 54,000 cubic yards.
Emergency Lagoons	These lagoons were most recently used as an influent pumping basin for the WWTP. The lagoons contain 12,000 cubic yards of primarily zinc hydroxide sludge.
Polishing Basins	These basins were used for settling of particulate materials produced during treatment of process wastewater in the WWTP. These basins are estimated to contain 16,500 cubic yards of primarily zinc hydroxide sludge.

AR302232

Table 2-4. Viscose basins operational history

Basin	Period of Operation	Volume of Viscose Disposed (cubic yards)	Elevations	
			Top of Dike	Bottom of Dike
1	1940 – 1942 [a]	11,111	530	520
2	1942 – 1943 [a]	14,074	531	521
3	1943 – 1944 [a]	14,815	533	523
4	1944 – 1945 [a]	14,815	528.5	518.5
5	1945 – 1946 [a]	21,852	528.5	518.5
6	1946 – 1950	54,815	530	515
7 [b]	1950 – 1958	42,222	530	515
8 [b]	1950 – 1958	--	530	515
9	1958 – 1983	121,111	526	492.5
10	1961 – 1972	141,852	526	492
11	1974 – 1983	100,741	530	506

Source: Geraghty and Miller (1988)

[a] First date given is the year of construction. The construction of the subsequent basin is assumed to be the time frame of use.

[b] Volume of sludge disposed in basin 7 is a summation for both basins 7 and 8.

Table 2-5. Average temperature and precipitation data for 1931–1960, Front Royal, VA

Month	Temperature (°F)	Precipitation (inches)
January	34.9	2.39
February	36.1	2.12
March	43.0	3.16
April	54.2	3.11
May	64.3	4.10
June	72.2	3.70
July	76.1	4.24
August	74.5	4.16
September	68.0	2.97
October	57.3	3.45
November	46.0	2.59
December	36.2	2.48
Average Annual	55.2	--
Total Annual	--	38.47

Source: Geraghty and Miller (1988)

Table 2-6. Data from onsite rain gauge

(All results are reported in inches)

Month	1992 Historical Rainfall	1993 Historical Rainfall	1994 Historical Rainfall	1995 Historical Rainfall	1996 Historical Rainfall	1997 Historical Rainfall	1998 Historical Rainfall	1999 Actual Rainfall	1992 - 1998 Average Rainfall
January	2.2	1.9	3.1	4.6	8.8	0.9	6.3	4.2	3.97
February	2	2.5	3.4	1.6	1.93	1.1	6.9	1.2	2.78
March	3.35	7.15	7.4	1.85	3.3	5.1	3.85	2.7	4.57
April	5.7	5.0	2.6	1.8	1.4	1.0	3.3	3.0	2.97
May	4	2.05	3.6	4.8	6.9	1.4	4.1	1.7	3.84
June	3	4.6	2.65	4.85	6.8	4.5	5.65	1.3	4.58
July	5.7	2.0	3.85	4.40	5.20	2.4	0.3	1.6	3.41
August	1.6	2.1	6.7	3.5	4.0	1.6	1.7	1.6	3.03
September	6.25	3.5	2.4	2.2	7.65	4.9	1.3		4.03
October	0.6	2.2	0.95	6.80	4.1	1.35	0.90		2.41
November	3	4.3	2.4	5.0	4.0	8.1	0.5		3.90
December	3.6	3.5	1.62	1.90	2.70	3.0	1.2		2.50
Totals to Date	41.0	40.8	40.7	43.3	56.8	35.4	36.0	17.3	42.0

AR302235

Table 3-1. Summary of chemicals evaluated in groundwater at the Avtex site[a]

Analyte	Number of Samples Analyzed	Samples above Detection Limit		Maximum Concentration Detected (µg/L)	Location of Maximum Detection (Well ID)	Date of Maximum Detection
		Number	Percent			
Inorganics						
Aluminum, total	193	186	96	51,700	303	2/22/94
Aluminum, dissolved	193	106	55	28,800	303	2/22/94
Antimony, total	193	28	15	1,750	216	4/13/94
Antimony, dissolved	193	38	20	911	116	2/10/94
Arsenic, total	246	173	70	7,960	014	4/6/94
Arsenic, dissolved	230	126	55	1,840	305	2/17/94
Barium, total	193	193	100	7,400	302	4/5/94
Barium, dissolved	193	192	99	5,400	315	4/14/94
Beryllium, total	193	57	30	5.5	014	4/6/94
Beryllium, dissolved	193	27	14	6.6	MW10	4/12/94
Cadmium, total	246	63	26	200	GM08	8/15/87
Cadmium, dissolved	230	13	6	9.2	117	2/2/94
Calcium, total	193	193	100	857,000	MW10	4/12/94
Calcium, dissolved	193	193	100	883,000	MW10	4/12/94
Chromium, total	193	97	50	1,400	303	2/22/94
Chromium, dissolved	193	58	30	340	116	2/10/94
Cobalt, total	193	106	55	1,000	MW09	2/9/94
Cobalt, dissolved	193	77	40	917	MW09	2/9/94
Copper, total	193	119	62	1,550	303	2/22/94
Copper, dissolved	193	65	34	175	203	2/2/94
Iron, total	246	246	100	4,920,000	303	2/22/94
Iron, dissolved	230	222	97	63,000	MW02	5/29/87
Lead, total	246	128	52	234	303	2/22/94
Lead, dissolved	230	62	27	180	177	5/29/87
Magnesium, total	246	245	100	255,000	PW04	8/15/87
Magnesium, dissolved	230	227	99	195,000	MW11	2/3/94
Manganese, total	246	240	98	26,700	303	2/22/94
Manganese, dissolved	230	218	95	32,000	MW02	5/29/87
Mercury, total	193	108	56	165	116	2/10/94
Mercury, dissolved	193	106	55	176	116	2/10/94
Nickel, total	193	142	74	1,920	116	2/10/94
Nickel, dissolved	193	109	56	1,870	116	2/10/94
Potassium, total	246	228	93	1,650,000	315	2/15/94
Potassium, dissolved	230	215	93	1,630,000	315	2/15/94
Selenium, total	193	70	36	48.5	013	2/2/94
Selenium, dissolved	193	55	28	30.8	MW11	4/11/94
Silver, total	193	10	5	474	MW11	4/11/94
Silver, dissolved	193	10	5	1,570	MW04	4/13/94
Sodium, total	246	246	100	18,900,000	MW09	4/14/94
Sodium, dissolved	230	230	100	18,300,000	MW09	4/14/94
Thallium, total	193	33	17	20	GM02A	1/27/94
Thallium, dissolved	193	14	7	24	305	2/17/94
Vanadium, total	193	79	41	1,010	MW09	4/14/94
Vanadium, dissolved	193	46	24	877	MW09	4/14/94
Zinc, total	246	148	60	13,000	GM08	8/15/87
Zinc, dissolved	230	196	85	9,590	MW09	4/14/94
Pesticides/PCBs						
Arochlor 1016	191	0	0	--	--	--
Arochlor 1221	191	0	0	--	--	--
Arochlor 1232	191	0	0	--	--	--
Arochlor 1242	191	0	0	--	--	--

Table 3-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit Number	Samples above Detection Limit Percent	Maximum Concentration Detected (µg/L)	Location of Maximum Detection (Well ID)	Date of Maximum Detection
Pesticides/PCBs (cont.)						
Arochlor 1248	191	0	0	--	--	--
Arochlor 1254	191	0	0	--	--	--
Arochlor 1260	191	0	0	--	--	--
Aldrin	191	13	7	0.013	010, 004	2/7/94, 2/8/94
α-BHC	191	5	3	0.0076	025	2/3/94
β-BHC	191	13	7	0.041	MW03	2/7/94
δ-BHC	191	1	1	0.0013	111	2/10/94
γ-BHC (lindane)	191	15	8	0.036	25	2/3/94
α-Chlordane	191	32	17	1.6	316	4/13/94
γ-Chlordane	191	9	5	2.2	316	4/13/94
p,p'-DDD	191	11	6	0.52	316	4/13/94
p,p'-DDE	191	19	10	0.14	PW02	4/7/94
p,p'-DDT	191	28	15	0.49	316	4/13/94
Dieldrin	191	20	10	3.5	316	4/13/94
Endosulfan (i)	191	5	3	0.027	MW09	4/14/94
Endosulfan (ii)	191	4	2	0.082	MW09	4/14/94
Endosulfan sulfate	191	5	3	0.17	316	4/13/94
Endrin	191	27	14	0.62	316	4/13/94
Endrin aldehyde	191	4	2	0.06	216	2/16/94
Endrin ketone	191	6	3	0.16	316	4/13/94
Heptachlor	191	10	5	0.11	316	4/13/94
Heptachlor epoxide	191	1	1	0.012	205	2/10/94
Methoxychlor	191	3	2	0.0091	MW09	2/9/94
Toxaphene	191	0	0	--	--	--
Semi-Volatile Organic Compounds						
Acenaphthene	204	0	0	--	--	--
Acenaphthylene	204	0	0	--	--	--
6-Amino hexanoic acid	2	2	100	6	021	2/4/94
Anthracene	193	0	0	--	--	--
1,2-Benzene carboxylic acid-diisooctyl ester	2	2	100	270	315	2/8/94
Benzeneacetic acid	4	4	100	530	GM02B	2/1/94
Benzenediol isomer	1	1	100	57	PW02	4/7/94
Benzo(a)anthracene	204	0	0	--	--	--
Benzo(a)pyrene	204	0	0	--	--	--
Benzo(b)fluoranthene	204	0	0	--	--	--
Benzo(g,h,i)perylene	204	0	0	--	--	--
Benzo(k)fluoranthene	204	0	0	--	--	--
Benzoic acid	35	28	80	1,000	315	4/14/94
Benzothiazole	2	2	100	7	GM01B	4/14/94
2-(2h-Benzotriazol-2-yl)-4-methyl-phenol	2	2	100	940	315	2/8/94
Benzyl alcohol	11	0	0	--	--	--
2,6-Bis(1,1-dimethylethyl)1,4-benzenediol	1	1	100	4	025	2/3/94
Bis(2-chloroethoxy)methane	204	0	0	--	--	--
Bis(2-chloroethyl)ether	204	0	0	--	--	--
Bis(2-chloroisopropyl)ether	11	0	0	--	--	--
Bis(2-ethylhexyl)phthalate	204	150	74	610	GM05	2/2/94
4-Bromophenyl phenyl ether	204	0	0	--	--	--
Butanoic acid	5	5	100	11,000	MW03, 305	2/7/94, 2/17/94
2-Butoxyethanol	1	1	100	28	GM06	2/4/94
2-(2-Butoxyethoxy)-ethanol	1	1	100	8	GM09	2/4/94
n-Butyl-benzenesulfonamide	4	4	100	40	GM04	2/10/94

Table 3-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit Number	Samples above Detection Limit Percent	Maximum Concentration Detected (µg/L)	Location of Maximum Detection (Well ID)	Date of Maximum Detection
Semi-Volatile Organic Compounds (cont.)						
Butylbenzylphthalate	204	1	0	6	316	4/13/94
Carbazole	193	0	0	--	--	--
Carboxylic acid isomers	1	1	100	6	GM03	4/12/94
Chlorinated propene isomer	1	1	100	6	GM09	4/11/94
4-Chloro-3-methyl-phenol	204	0	0	--	--	--
4-Chloroaniline	204	0	0	--	--	--
Chloroethanol phosphate	1	1	100	48	109	4/12/94
2-Chloronaphthalene	204	0	0	--	--	--
2-Chlorophenol	204	0	0	--	--	--
4-Chlorophenyl-phenylether	204	0	0	--	--	--
Chloropropene isomer	1	1	100	24	MW05	4/13/94
Chrysene	204	0	0	--	--	--
Cyclohexene-1-one isomer	3	3	100	4	120	4/11/94
Dibenz(a,h)anthracene	204	0	0	--	--	--
Dibenzofuran	204	0	0	--	--	--
1,2-Dichlorobenzene	204	2	1	2	MW04	2/4/94
1,3-Dichlorobenzene	204	0	0	--	--	--
1,4-Dichlorobenzene	204	2	1	2	MW04	2/4/94
3,3'-Dichlorobenzidine	204	0	0	--	--	--
2,4-Dichlorophenol	204	0	0	--	--	--
Dichloropropene isomer	1	1	100	5	GM01B	4/14/94
Diethyl phthalate	204	12	6	3	GM05, 024, 315	2/2/94, 4/7/94, 4/14/94
Dimethyl phthalate	204	2	1	3	204	2/3/94
n,n-Dimethyl formamide	1	1	100	6	177	4/5/94
2,4-Dimethyl-phenol	204	4	2	10	MW09	4/14/94
Di-n-butyl phthalate	193	1	1	1	PZ10	2/4/94
4,6-Dinitro-2-methyl-phenol	204	0	0	--	--	--
2,4-Dinitrophenol	204	0	0	--	--	--
2,4-Dinitrotoluene	204	0	0	--	--	--
2,6-Dinitrotoluene	204	1	0	18	315	2/8/94
Di-n-octyl phthalate	204	0	0	--	--	--
Dodecanoic acid	1	1	100	10	GM05	2/2/94
Ethyl hexanoic acid	1	1	100	150	109	4/12/94
Ethyl pentenoat	1	1	100	48	MW12	4/12/94
2-Ethyl-hexanoic acid	2	2	100	640	315	2/8/94
Fluoranthene	193	0	0	--	--	--
Fluorene	204	0	0	--	--	--
Heptanone	1	1	100	81	109	4/12/94
Hexachlorobenzene	204	0	0	--	--	--
Hexachlorobutadiene	204	0	0	--	--	--
Hexachlorocyclopentadiene	204	0	0	--	--	--
Hexachloroethane	204	0	0	--	--	--
Hexadecanoic acid	2	2	100	460	MW09	2/9/94
Hexamethylcyclotrisiloxane	2	2	100	2	017	2/3/94
Hexanoic acid	1	1	100	3	GM07	4/12/94
Hexathiepane	2	2	100	66	GM02A	1/27/94
Hexen-1-ol	1	1	100	14	GM04	4/12/94
Hydroxy biphenyl isomer	2	2	100	17	MW12	4/12/94
4-Hydroxy-4-methyl-2-pentanone	1	1	100	62	PZ01	1/18/94
8-Hydroxyoctanoic acid	2	2	100	16	302	1/26/94
Indeno(1,2,3-cd)pyrene	204	0	0	--	--	--
Isocrotonic acid	1	1	100	6	201	4/6/94

Table 3-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit: Number	Samples above Detection Limit: Percent	Maximum Concentration Detected (µg/L)	Location of Maximum Detection (Well ID)	Date of Maximum Detection
Semi-Volatile Organic Compounds (cont.)						
Isophorone	204	0	0	--	--	--
Methyl propanoic acid	1	1	100	4	GM03	4/12/94
3-Methyl-1h-indole	1	1	100	46	GM02B	2/1/94
5-Methyl-2,4-diisopropylphenol	2	2	100	5	025	2/3/94
Methylated formamide	1	1	100	50	PW02	4/7/94
Methylated urea compound	3	3	100	3	011	4/4/94
2-Methyl-butanoic acid	1	1	100	35	GM02B	2/1/94
3-Methyl-butanoic acid	1	1	100	1,800	MW03	2/7/94
4,4'-(1-Methylethylidene)bis-phenol	1	1	100	13	204	2/3/94
2-Methyl-naphthalene	204	3	1	1	GM02B, GM05, MW09	2/1/94, 2/2/94, 2/9/94
Methylpentenediol isomer	1	1	100	5	201	4/6/94
2-Methyl-phenol	204	23	11	380	MW09	4/14/94
4-Methyl-phenol	204	43	21	1,600	GM02B	2/1/94
2-Methyl-propanoic acid	1	1	100	1,500	MW03	2/7/94
Mono(2-ethylhexyl)ester-(9cl)-hexanedioic a	1	1	100	240	GM05	2/2/94
Naphthalene	204	6	3	8	MW12	4/12/94
2-Nitroaniline	204	0	0	--	--	--
3-Nitroaniline	204	0	0	--	--	--
4-Nitroaniline	204	0	0	--	--	--
Nitrobenzene	204	1	0	96	316	4/13/94
2-Nitrophenol	204	0	0	--	--	--
4-Nitrophenol	204	1	0	19	116	4/13/94
n-Nitroso-di-k-propylamine	6	0	0	--	--	--
n-Nitroso-di-n-propylamine	193	0	0	--	--	--
n-Nitrosodiphenylamine	204	0	0	--	--	--
n-Nitroso-dipropylamine	5	0	0	--	--	--
Nonanedioic acid	1	1	100	110	302	1/26/94
Octanoic acid	1	1	100	270	MW03	2/7/94
Oxindol	1	1	100	130	GM02B	2/1/94
2,2'-Oxybis(1-chloropropane)	193	0	0	--	--	--
Pentachlorophenol	199	6	3	50	GM09, GM05, PW03	8/15/87
Pentanoic acid	1	1	100	260	MW03	2/7/94
Phenanthrene	193	2	1	8	MW09	4/14/94
Phenol	204	59	29	82,000	MW3	5/29/87
Phenolics, total	53	13	25	29,000	GM2B	8/15/87
Phenols	38	14	37	22,000	GM08	5/29/87
Phenylene ethanone isomers	1	1	100	20	PW03	4/7/94
1,1'-(1,3-Phenylene)bis-ethanone	1	1	100	8	304	2/16/94
Pyrene	198	0	0	--	--	--
Sulfur, mol.	18	18	100	4,100	PZ11	2/8/94
Tetramethyl-urea	2	2	100	27	MW11	2/3/94
7-Thiabicyclo [4.1.0] heptane	1	1	100	5	PZ02	1/17/94
Thiophenecarboxylic acid	1	1	100	79	GM02A	1/27/94
2-Thiophenecarboxylic acid	3	3	100	150	205	2/10/94
1,2,4-Trichlorobenzene	204	0	0	--	--	--
2,4,5-Trichlorophenol	204	0	0	--	--	--
2,4,6-Trichlorophenol	204	0	0	--	--	--
1,2,3-Trimethyl-benzene	1	1	100	3	GM01A	2/3/94

Table 3-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit Number	Samples above Detection Limit Percent	Maximum Concentration Detected (µg/L)	Location of Maximum Detection (Well ID)	Date of Maximum Detection
Volatile Organic Compounds						
Acetic acid	1	1	100	7	PZ11	4/8/94
Acetone	291	91	31	240,000	177	5/29/87
Benzene	291	4	1	6	MW12	2/4/94, 4/12/94
Bromodichloromethane	291	1	0	1	304	10/18/93
Bromoform	291	0	0	--	--	--
Bromomethane	291	1	0	3	304	2/16/94
2-Butanone	291	27	9	8,600	116	2/10/94
Carbon disulfide	380	205	54	5,100,000 [b]	GM08	5/29/87
Carbon tetrachloride	291	0	0	--	--	--
Chlorobenzene	291	0	0	--	--	--
Chloroethane	291	0	0	--	--	--
2-Chloroethylvinylether	15	0	0	--	--	--
Chloroform	291	20	7	18	302	8/23/93
Chloromethane	291	0	0	--	--	--
Cyanide, total	193	30	16	5,096	GM02A	1/27/94
Cyclopentanol	1	1	100	18	PW01	2/8/94
Dibromochloromethane	291	0	0	--	--	--
1,1-Dichloroethane	291	0	0	--	--	--
1,2-Dichloroethane	567	0	0	--	--	--
trans-1,2-Dichloroethene	15	0	0	--	--	--
1,1-Dichloroethylene	291	0	0	--	--	--
1,2-Dichloropropane	291	0	0	--	--	--
cis-1,3-Dichloropropene	291	0	0	--	--	--
trans-1,3-Dichloropropene	291	0	0	--	--	--
Ethylbenzene	291	4	1	2	GM05, MW12	2/2/94, 4/12/94
Heptanal	1	1	100	5	PW01	2/8/94
2-Heptanone	2	2	100	23	315	2/3/94
Hexanal	2	2	100	200	PW01	2/8/94
2-Hexanone	291	10	3	1,000	GM09	8/15/87
Methanethiol	2	2	100	40	177	1/31/94
Methyl dioxolane	1	1	100	9	PZ02	4/8/94
2-Methyl-1,3-dioxolane	3	3	100	7	MW04	2/4/94
4-Methyl-2-pentanone	291	7	2	1,000	GM09	8/15/87
Methylene chloride	291	52	18	30,000	GM02B	5/29/87
3-Octanone	1	1	100	19	PW01	2/8/94
Oxybis-methane	1	1	100	210	177	1/31/94
Pentane	1	1	100	9	PW01	2/8/94
2-Propanol	1	1	100	5	315	2/3/94
Styrene	291	0	0	--	--	--
Sulfur dioxide	5	5	100	1,500	GM02B	2/1/94
1,1,2,2-Tetrachloroethane	291	0	0	--	--	--
Tetrachloroethylene	291	0	0	--	--	--
Thiobis-methane	1	1	100	5	GM09	2/4/94
Toluene	291	37	13	46	GM06	2/4/94
1,1,2-Trichloro-1,2,2-trifluoroethane	1	1	100	5	112	2/1/94
1,1,1-Trichloroethane	291	0	0	--	--	--
1,1,2-Trichloroethane	291	0	0	--	--	--
Trichloroethene	291	1	0	2	302	8/23/93
Vinyl acetate	15	0	0	--	--	--
Vinyl chloride	291	1	0	1	MW07	2/4/94
Xylenes, total	291	7	2	1,800	PW02	2/8/94

Table 3-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit Number	Samples above Detection Limit Percent	Maximum Concentration Detected (µg/L)	Location of Maximum Detection (Well ID)	Date of Maximum Detection
Miscellaneous						
Ammonia nitrogen	54	33	61	22,000	305	2/17/94
Carbonate (as $CaCO_3$)	54	11	20	21,300,000	116	2/10/94
Chloride	109	108	99	1,900,000	MW10	8/15/87
Chloride (titrimetric)	34	34	100	12,000,000	116	2/10/94
Hydroxide	17	0	0	--	--	--
Nitrate	53	28	53	7,100	MW09	8/15/87
Nitrate nitrogen	37	9	24	40,000	116	2/10/94
Nitrate/nitrite	55	42	76	15,100	024	2/7/94
Nitrite nitrogen	37	4	11	80	203	2/2/94
pH (s.u.)	90	90	100	11	GM08	8/15/87
Sulfate	107	107	100	7,400,000	GM08	5/29/87
Sulfate (turbidimetric)	37	37	100	6,000,000	116	2/10/94
Sulfide	144	85	59	7,200,000	GM08	8/15/87
Total dissolved solids	144	144	100	93,000,000	GM08	5/29/87

Note -- - not applicable

[a] Table summarizes all groundwater data collected to date.

[b] A concentration of 310,000 mg/L of carbon disulfide was reported for a May 1987 groundwater sample from well GM-2B. However, this value appears to be incorrect, and may be an error in reporting units (mg/L instead of µg/L).

Table 3-2. Summary of chemicals in viscose sludge in viscose basins 9, 10, and 11[a]

Analyte	Number of Samples Analyzed	Number of Samples above Detection Limit	Maximum Concentration Detected (mg/kg)	Location of Maximum Detection (Bore Hole ID)	Location of Maximum Detection (Basin ID)	Date of Maximum Detection
Inorganics						
Aluminum	8	8	11,200	AV-VB-BH-37-20	VB-09	9/22/93
Antimony	45	28	11	AV-VB-BH-38-14	VB-09	10/12/93
Arsenic	96	46	59	AV-VB-BH-37-00	VB-09	9/22/93
Barium	45	39	4,500	AV-VB-BH-37-25	VB-09	9/22/93
Beryllium	45	1	0.49	AV-VB-BH-37-20	VB-09	9/22/93
Cadmium	96	19	22.4	AV-VB-BH-37-07	VB-09	9/22/93
Calcium	45	41	20,000	AV-VB-BH-38-00	VB-09	10/12/93
Chromium	82	27	83	AV-VB-BH-44-00	VB-10	10/14/93
Cobalt	45	12	38	AV-VB-BH-38-14	VB-09	10/12/93
Copper	45	41	520	AV-VB-BH-37-00	VB-09	9/22/93
Iron	59	58	44,000	AV-VB-BH-43-20	VB-10	9/20/93
Lead	96	56	1,000	AV-VB-BH-36-18	VB-09	9/21/93
Magnesium	22	19	2,300	GM-VB-SS10	VB-10	9/2/87
Manganese	59	49	980	GM-VB-BH9	VB-09	8/27/87
Mercury	45	2	0.56	AV-VB-BH-40-00	VB-11	9/30/93
Nickel	45	30	33	AV-VB-BH-37-00	VB-09	9/22/93
Potassium	59	35	34,000	AV-VB-BH-39-17	VB-11	9/29/93
Selenium	45	23	4.2	AV-VB-BH-37-00	VB-09	9/22/93
Silver	45	14	6	AV-VB-BH-41-10	VB-11	10/13/93
Sodium	22	22	113,000	GM-VB-BH11	VB-11	8/24/87
Thallium	45	30	62	AV-VB-BH-36-18	VB-09	9/21/93
Vanadium	45	35	220	AV-VB-BH-37-00	VB-09	9/22/93
Zinc	96	81	18,000	AV-VB-BH-36-18	VB-09	9/21/93
Pesticides/PCBs						
Arochlor 1016	45	0	--	--	--	--
Arochlor 1221	45	0	--	--	--	--
Arochlor 1232	45	0	--	--	--	--
Arochlor 1242	67	0	--	--	--	--
Arochlor 1248	67	0	--	--	--	--
Arochlor 1254	67	0	--	--	--	--
Arochlor 1260	67	0	--	--	--	--
Aldrin	45	0	--	--	--	--
α-BHC	45	0	--	--	--	--
β-BHC	45	0	--	--	--	--
δ-BHC	45	1	0.56	AV-VB-BH-43-12	VB-10	9/20/93
γ-BHC (lindane)	45	1	0.21	AV-VB-BH-43-00	VB-10	9/20/93
α-Chlordane	45	0	--	--	--	--
γ-Chlordane	45	1	0.044	AV-VB-BH-43-12	VB-10	9/20/93
Dieldrin	45	0	--	--	--	--
Endosulfan (i)	45	0	--	--	--	--
Endosulfan (ii)	45	0	--	--	--	--
Endosulfan sulfate	45	0	--	--	--	--
Endrin	45	0	--	--	--	--
Endrin aldehyde	45	0	--	--	--	--
Endrin ketone	45	0	--	--	--	--
Heptachlor	45	0	--	--	--	--

Table 3-2. (cont.)

Analyte	Number of Samples Analyzed	Number of Samples above Detection Limit	Maximum Concentration Detected (mg/kg)	Location of Maximum Detection (Bore Hole ID)	(Basin ID)	Date o Maximum Detection
Pesticides/PCBs (cont.)						
Heptachlor epoxide	45	0	--	--	--	--
Methoxychlor	45	0	--	--	--	--
p,p'-DDD	45	0	--	--	--	--
p,p'-DDE	45	0	--	--	--	--
p,p'-DDT	45	0	--	--	--	--
Toxaphene	44	0	--	--	--	--
Semi-Volatile Organic Compounds						
Acenaphthene	55	0	--	--	--	--
Acenaphthylene	55	0	--	--	--	--
Acetic acid	1	1	1	AV-VB-BH-44-00	VB-10	10/14/93
Anthracene	55	0	--	--	--	--
1,2-Benzene carboxylic acid-diisooctyl ester	1	1	2.2	AV-VB-BH-40-10	VB-11	9/30/93
Benzo(a)anthracene	55	0	--	--	--	--
Benzo(a)pyrene	55	0	--	--	--	--
Benzo(b)fluoranthene	55	0	--	--	--	--
Benzo(g,h,i)perylene	55	0	--	--	--	--
Benzo(k)fluoranthene	55	0	--	--	--	--
Benzoic acid	11	2	0.19	GM-VB-BH11	VB-11	8/24/87
Benzyl alcohol	10	0	--	--	--	--
Bis(2-chloroethoxy)methane	55	0	--	--	--	--
Bis(2-chloroethyl)ether	55	0	--	--	--	--
Bis(2-chloroisopropyl)ether	47	0	--	--	--	--
Bis(2-ethylhexyl)phthalate	58	5	1	GM-VB-BH9	VB-09	8/27/87
4-Bromophenyl phenyl ether	55	0	--	--	--	--
Butylbenzylphthalate	55	0	--	--	--	--
Carbazole	45	0	--	--	--	--
4-Chloro-3-methyl-phenol	55	0	--	--	--	--
4-Chloroaniline	55	0	--	--	--	--
2-Chloronaphthalene	55	0	--	--	--	--
2-Chlorophenol	55	0	--	--	--	--
4-Chlorophenyl-phenylether	55	0	--	--	--	--
Chrysene	55	0	--	--	--	--
Coryan 17-ol 18,19 d.dehydro-10-met	1	1	0.9	AV-VB-BH-44-00	VB-10	10/14/93
Dibenz(a,h)anthracene	55	0	--	--	--	--
Dibenzofuran	55	0	--	--	--	--
1,2-Dichlorobenzene	55	0	--	--	--	--
1,3-Dichlorobenzene	55	0	--	--	--	--
1,4-Dichlorobenzene	55	0	--	--	--	--
3,3'-Dichlorobenzidine	55	0	--	--	--	--
2,4-Dichlorophenol	55	0	--	--	--	--
Diethyl phthalate	55	1	0.22	AV-VB-BH-37-20	VB-09	9/22/93
Dimethyl phthalate	92	1	0.25	AV-VB-BH-42-13	VB-10	9/20/93
2,4-Dimethyl-phenol	55	0	--	--	--	--
Di-n-butyl phthalate	45	0	--	--	--	--
4,6-Dinitro-2-methyl-phenol	55	0	--	--	--	--

Table 3-2. (cont.)

Analyte	Number of Samples Analyzed	Number of Samples above Detection Limit	Maximum Concentration Detected (mg/kg)	Location of Maximum Detection (Bore Hole ID)	Location of Maximum Detection (Basin ID)	Date of Maximum Detection
Semi-Volatile Organic Compounds (cont.)						
2,4-Dinitrophenol	55	0	--	--	--	--
2,4-Dinitrotoluene	55	0	--	--	--	--
2,6-Dinitrotoluene	55	0	--	--	--	--
Di-n-octyl phthalate	57	1	0.53	AV-VB-BH-37-07	VB-09	9/22/93
Dodecanamide,n,n-bis(2-hydroxyethyl)	3	3	13	AV-VB-BH-37-07	VB-09	9/22/93
Ethanol-2-2-2-phenoxyethoxy	1	1	3	AV-VB-BH-37-20	VB-09	9/22/93
Ethanol-2-phenoxy	2	2	29	AV-VB-BH-42-00	VB-10	9/20/93
Fluoranthene	45	0	--	--	--	--
Fluorene	55	0	--	--	--	--
Hexachlorobenzene	55	0	--	--	--	--
Hexachlorobutadiene	55	0	--	--	--	--
Hexachlorocyclopentadiene	55	0	--	--	--	--
Hexachloroethane	55	0	--	--	--	--
Hexadecanoic acid	3	3	3	AV-VB-BH-37-20	VB-09	9/22/93
4-Hydroxy-4-methyl-2-pentanone	1	1	2,300	AV-VB-BH-41-10	VB-11	10/13/93
Indeno(1,2,3-cd)pyrene	55	0	--	--	--	--
Isophorone	55	0	--	--	--	--
Lethionine	10	10	63	AV-VB-BH-37-07	VB-09	9/22/93
2-Methoxyethoxy-benzene	2	2	46	AV-VB-BH-37-07	VB-09	9/22/93
2-Methyl-naphthalene	55	0	--	--	--	--
2-Methyl-phenol	55	1	0.78	AV-VB-BH-37-20	VB-09	9/22/93
4-Methyl-phenol	93	25	2.9	AV-VB-BH-37-00	VB-09	9/22/93
1-Naphthalenamine n-phenyl	2	2	4.2	AV-VB-BH-43-12	VB-10	9/20/93
Naphthalene	92	0	--	--	--	--
2-Nitroaniline	55	0	--	--	--	--
3-Nitroaniline	55	0	--	--	--	--
4-Nitroaniline	55	0	--	--	--	--
Nitrobenzene	55	0	--	--	--	--
2-Nitrophenol	55	0	--	--	--	--
4-Nitrophenol	55	0	--	--	--	--
n-Nitroso-di-n-propylamine	55	0	--	--	--	--
n-Nitrosodiphenylamine	55	0	--	--	--	--
Octadecanoil	1	1	4.3	AV-VB-BH-44-00	VB-10	10/14/93
14-Octadecenoic acid methylester	1	1	2.8	AV-VB-BH-37-20	VB-09	9/22/93
2,2'-Oxybis(1-chloropropane)	8	0	--	--	--	--
Pentachlorophenol	56	0	--	--	--	--
Phenanthrene	56	4	0.7	GM-VB-BH9	VB-09	8/27/87
Phenol	96	68	15,000	GM-VB-BH10	VB-10	8/19/87
Phenols	14	7	81	GM-VB-BH9	VB-09	8/26/87
Pyrene	82	17	20	AV-VB-BH-36-00	VB-09	9/21/93
Sulfur	1	1	170	AV-VB-BH-41-03	VB-11	10/13/93
Sulfur, mol. (s8)	6	6	97	AV-VB-BH-42-00	VB-10	9/20/93
Tetrathiane isomer	1	1	14	AV-VB-BH-37-07	VB-09	9/22/93
1,2,4,5-Tetrathiane	2	2	14	AV-VB-BH-36-03	VB-09	9/21/93
1,2,4,6-Tetrathiepane	3	3	7.9	AV-VB-BH-36-03	VB-09	9/21/93
1,3,5,7-Tetrathiocane	1	1	1.9	AV-VB-BH-36-03	VB-09	9/21/93

Table 3-2. (cont.)

Analyte	Number of Samples Analyzed	Number of Samples above Detection Limit	Maximum Concentration Detected (mg/kg)	Location of Maximum Detection (Bore Hole ID)	(Basin ID)	Date o Maximum Detection
Semi-Volatile Organic Compounds (cont.)						
1,2,4-Trichlorobenzene	55	0	--	--	--	--
2,4,5-Trichlorophenol	55	0	--	--	--	--
2,4,6-Trichlorophenol	55	0	--	--	--	--
1,3,5-Trimethyl-benzene	3	3	95	AV-VB-BH-36-03	VB-09	9/21/93
1,3,5-Trithiane	2	2	220	AV-VB-BH-37-07	VB-09	9/22/93
1,2,4-Trithiolane-3,5-dimethyl	1	1	2.2	AV-VB-BH-36-03	VB-09	9/21/93
Undecane	1	1	54	AV-VB-BH-37-20	VB-09	9/22/93
Volatile Organic Compounds						
Acetone	65	16	2,000	GM-VB-BH11	VB-11	8/24/87
Benzene	65	0	--	--	--	--
Bromodichloromethane	65	0	--	--	--	--
Bromoform	65	0	--	--	--	--
Bromomethane	65	0	--	--	--	--
2-Butanone	65	7	7.7	GM-VB-BH11	VB-11	8/24/87
Carbon disulfide	66	62	20,000	GM-VB-BH11	VB-11	8/24/87
Carbon tetrachloride	65	0	--	--	--	--
Chlorobenzene	65	0	--	--	--	--
Chloroethane	65	0	--	--	--	--
2-Chloroethylvinylether	20	0	--	--	--	--
Chloroform	65	0	--	--	--	--
Chloromethane	65	0	--	--	--	--
Cyanide (reactivity)	2	0	--	--	--	--
Cyanide, total	38	9	17.2	AV-VB-BH-40-00	VB-11	9/30/93
Decane	2	2	12	AV-VB-BH-36-24	VB-09	9/21/93
Dibromochloromethane	65	0	--	--	--	--
1,1-Dichloroethane	65	0	--	--	--	--
1,2-Dichloroethane	65	0	--	--	--	--
trans-1,2-Dichloroethene	20	0	--	--	--	--
1,1-Dichloroethylene	65	0	--	--	--	--
1,2-Dichloropropane	65	0	--	--	--	--
cis-1,3-Dichloropropene	65	0	--	--	--	--
trans-1,3-Dichloropropene	65	0	--	--	--	--
Ethylbenzene	65	0	--	--	--	--
2-Hexanone	65	6	7.7	GM-VB-BH11	VB-11	8/24/87
4-Methyl-2-pentanone	65	13	1,500	GM-VB-SS11	VB-11	9/2/87
Methylene chloride	65	29	450	GM-VB-BH10	VB-10	8/20/87
Propyl-cyclohexane	1	1	0.062	AV-VB-BH-43-00	VB-10	9/20/93
Styrene	65	0	--	--	--	--
1,1,2,2-Tetrachloroethane	65	0	--	--	--	--
Tetrachloroethylene	65	3	450	GM-VB-BH10	VB-10	8/20/87
Toluene	65	10	2.2	AV-VB-BH-37-07	VB-09	9/22/93
1,1,1-Trichloroethane	65	0	--	--	--	--
1,1,2-Trichloroethane	65	0	--	--	--	--
Trichloroethene	65	0	--	--	--	--
1,2,3-Trimethyl-benzene	1	1	3.7	AV-VB-BH-37-20	VB-09	9/22/93
1,2,4-Trimethyl-benzene	1	1	6.9	AV-VB-BH-43-12	VB-10	9/20/93

Table 3-2. (cont.)

Analyte	Number of Samples Analyzed	Number of Samples above Detection Limit	Maximum Concentration Detected (mg/kg)	Location of Maximum Detection (Bore Hole ID)	(Basin ID)	Date of Maximum Detection
Volatile Organic Compounds (cont.)						
1,3,5-Trimethyl-benzene	1	1	13	AV-VB-BH-37-20	VB-09	9/22/93
Vinyl acetate	20	0	--	--	--	--
Vinyl chloride	65	0	--	--	--	--
Xylenes, total	65	2	0.019	GM-VB-SS9	VB-09	8/27/87
Miscellaneous						
Acidity, (as $CaCO_3$)	1	0	--	--	--	--
Alkalinity, total	1	1	59,000	AV-VB-BH-39-15	VB-11	9/29/93
Bicarbonate	1	1	7,000	AV-VB-BH-39-15	VB-11	9/29/93
Carbonate	1	1	52,000	AV-VB-BH-39-15	VB-11	9/29/93
Hydroxide	1	0	--	--	--	--
Moisture content	53	53	91	AV-VB-BH-40-00	VB-11	9/30/93
Sulfide (reactivity)	4	4	5,970	AV-VB-BH-44-00	VB-10	10/14/93
Total organic carbon	6	6	120,000	AV-VB-BH-39-10	VB-11	9/29/93

Note -- - not applicable

[a] Table summarizes all viscose sludge data collected to date.

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Table 3-3. Summary of detected analytes in pore water and seeps in viscose basins 9, 10, and 11[a]

Analyte	VB-09 (pore water)	VB-11 (pore water)	VB-10 (seep water)
Inorganics			
Iron (µg/L)	445	445	445
Magnesium (µg/L)	4,450	ND	4,450
Manganese (µg/L)	20	20 U	20 U
Potassium (mg/L)	14	23	230
Sodium (mg/L)	10,000	15,000	9,800
Zinc (µg/L)	800	800	800
Semi-Volatile Organic Compounds (µg/L)			
Benzoic acid	ND	ND	300 J
Diethyl phthalate	ND	ND	200 J
4-Methyl-phenol	85 J	470	ND
Phenanthrene	60 J	ND	ND
Phenol	5,650	3,200	7,700
Phenols	13	70	20
Volatile Organic Compounds (µg/L)			
Acetone	300,000	ND	1,000,000 B
2-Butanone	40,000 JB	ND	ND [b]
Carbon disulfide	700,000	3,431,000	285,000
Methylene chloride	140,000 JB	ND [b]	135,000 J
Tetrachloroethylene	50,000	ND	ND
Toluene	ND	ND	130,000 J
Miscellaneous			
Alkalinity (mg/L)	18,000 L	32,000 L	14,000 L
Chemical oxygen demand (mg/L)	4,650	12,800	3,900
Chloride (mg/L)	205	130	360
Conductivity (µmhos)	36.7	71	39.3
pH (s.u.)	10.255 L	10.255 L	10.255 L
Sulfate (mg/L)	3,300	2,600	4,200
Total dissolved solids (mg/L)	25,950 L	45,500 L	26,900 L

Note: B - not detected substantially above (10x) the level reported in the laboratory or field blanks (includes field, trip, rinsate, and equipment blanks).
J - analyte present. Reported value is estimated. Concentration is below the level for accurate quantitation.
L - analyte present. Reported value may be biased low. Actual value is expected to be higher.
U - non-detect. Reported value is the detection limit.

[a] Only a single pore/seep water sample was collected from each of viscose basins 9, 10, and 11. For the volatile organic compounds, values for VB-09 and VB-10 are averages of duplicates. Only analytes that were detected in one or more of viscose basins 9, 10, or 11 are reported in this table.

[b] Qualified as UB.

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Table 3-4. Potential sources within the plant area

Potential Areas of Concern	Chemicals	Reference
Main Plant Building	Potentially all site chemicals have been handled in the main building.	Halliburton NUS/ Gannett Fleming, Inc. 1993
Sewer Systems	Potentially all site chemicals could have been transported within the sewer system.	Halliburton NUS/ Gannett Fleming, Inc. 1993
East and West Carbon Disulfide Storage Area	CS_2	ERM 1994
Aboveground Storage Tanks	SO_4, Zn, Elevated pH, TPH	ERM 1994; Halliburton NUS/ Gannett Fleming, Inc. 1993
Underground Storage Tanks	SO_4, BTEX, TPH	ERM 1994
Boneyard	VOCs, Phenols, BEHP, PAHs, PCBs, Pesticides, Metals	ERM 1994
Zinc Recovery Building	Zn	ERM 1994
Lead Casting Shop	Pb	ERM 1994
Polypropylene Loading Dock	PCBs	ERM 1994
Acid Reclaim Building	BEHP, Phenols, Metals	ERM 1994
Paint Shop	VOCs	ERM 1994
Chemical Storage Area	BEHP, PCBs, PAHs, Zn	ERM 1994
Coal Yard	PCBs	ERM 1994
Acid Reclaim Cooling Tower	Cr	ERM 1994
Spray Ponds	Cr	ERM 1994

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Table 4-1. Summary of risk-based screening of chemicals in groundwater at the Avtex site

EPA Region III RBC Screening Results	Concentration-Toxicity Screening Results
Inorganics	**Inorganics**
Aluminum	Antimony
Antimony	Arsenic
Arsenic	Cadmium
Barium	Chromium
Cadmium	Iron
Chromium	Manganese
Cobalt	Mercury
Copper	Ammonia nitrogen
Iron	
Manganese	
Mercury	
Nickel	
Selenium	
Silver	
Thallium	
Vanadium	
Zinc	
Ammonia nitrogen	
Pesticides/PCBs	**Pesticides/PCBs**
Aldrin	None
β-HCH	
α-Chlordane	
γ-Chlordane	
Dieldrin	
p,p'-DDD	
p,p'-DDT	
Heptachlor	
Heptachlor epoxide	
Semi-Volatile Organic Compounds	**Semi-Volatile Organic Compounds**
Bis(2-ethylhexyl)phthalate	None
1,4-Dichlorobenzene	
2,6-Dinitrotoluene	
2-Methyl-phenol	
4-Methyl-phenol	
Naphthalene	
Nitrobenzene	
Pentachlorophenol	
Phenol	
Volatile Organic Compounds	**Volatile Organic Compounds**
Acetone	Carbon disulfide
Benzene	
Bromodichloromethane	
Bromomethane	
2-Butanone	
Carbon disulfide	
Chloroform	
Cyanide	
Methylene chloride	
Trichloroethene	
Vinyl chloride	
Xylenes, total	

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Table 5-1. Federal applicable or relevant and appropriate requirements

Requirements	Description	Category
Chemical-Specific		
Clean Water Act (PL92-5090) - Federal Ambient Water Quality Criteria.	Response actions may result in surface water discharges to river. These criteria are relevant to treated water and surface water discharges.	Relevant and Appropriate
Clean Air Act (42 USC 7401) - Nation Ambient Air Quality Standards (NAAQS) (40 CFR Part 5).	Response action may result in the release of particulate contaminants to the air. Standards for particulate are applicable.	Applicable
Site-Specific Effluent Limits for the discharge of treated water from the WWTP.	Response action may result in water being treated in the WWTP. Treated effluent must meet the effluent limits in the AOC.	Applicable
Safe Drinking Water Act - Maximum Contaminant Levels (MCLs). - Maximum Contaminate Level Goals (MCLGs).	Response action may include groundwater cleanup to MCLs, SARA 121(d)(2)(A)(ii). MCLGs are to be considered (TBC) during remediation.	Relevant and Appropriate
U.S. EPA Region III Risk-Based Concentrations - Tap Water Standards. - Industrial Soil Standards.	Applicable during the remediation of groundwater and viscose basins 9, 10, and 11.	Relevant and Appropriate
General Pretreatment Regulation for Existing and New Sources of Pollution (40 CFR Part 403).	Considered for remedial alternatives involving pretreatment of groundwater prior to treatment by a POTW.	Applicable
Location-Specific		
Flood plain management (Executive Order I 1988). Section 10 of the Rivers and Harbors Act. Section 404 of the Clean Water Act.	Project may be located within the 100-year floodplain. Effects of response action on the navigable water of the U.S. need to be considered. The design of the response action will delineate measures to minimize potential adverse floodplain impacts.	Applicable
Flood Disaster Protection Act of 1973 and National Flood Insurance Act of 1968.	Project may be located within the 100-year floodplain and floodplain resources may be affected by the response action. If federal assistance is sought for any project in the floodplain, flood insurance coverage will need to be obtained.	Applicable
Protection of Wetlands (Executive Order I 1990). Section 404 of the Clean Water Act.	Project may be located within the 100-year floodplain. The response action may affect wetland resources.	Applicable
Fish and Wildlife Conservation Act of 1980 (16 USC 2901).	The goal of the Act is to conserve and promote the conservation of non-game fish and wildlife and their habitats. The response action to close the basins is likely to eliminate the exposure pathway, thereby promoting conservation. Coordination with state and federal authorities to inventory species and ensure that actions taken will conserve valued species and their habitats.	Relevant and Appropriate

Table 5-1. (cont.)

Requirements	Description	Category
Location-Specific (cont.)		
Fish and Wildlife Coordination Act (16 USC 661-667c).	Response action may affect fish and wildlife habitat present on-site. The Act requires wildlife conservation equal in consideration with other features during the response action process that may impact water bodies (including wetlands). Consultation with the appropriate state and federal agencies for the purpose of preventing loss of and damage to wildlife resources will need to be performed.	Relevant and Appropriate
Fish and Wildlife Migratory Bird Treaty Act (16 USC 701).	The Act provides for the protection of migratory birds from harm. The response action to close the basins is likely to eliminate the exposure pathway, thereby protecting migratory birds.	Relevant and Appropriate
Wild and Scenic Rivers Act (36 CFR 297.4).	Site is adjacent to the South Fork of the Shenandoah River. Although the River is not a listed Wild and Scenic River, it is used for recreational purposes. The design of the response action will assess if the action will result in conditions that are inconsistent with the usage of the River.	Relevant and Appropriate
Groundwater Protections Strategy.	Remedial alternatives may be evaluated based on class designation.	Relevant and Appropriate
Action-Specific		
OSHA Requirements (29 CFR, Parts 1910, 1926, and 1904).	Protection for workers engaged in response action implementation is required.	Applicable
Threshold Limit Values. American Conference of Governmental Industrial Hygienists.	Applicable to air concentrations during response action implementation.	Applicable
Hazardous Waste Requirements (RCRA Subtitle C, 40 CFR Part 261–264).	Standards applicable to identifying, treating, storing, and disposing of hazardous wastes.	Relevant and Appropriate
RCRA Land Ban Requirements (40 CFR Part 268).	Response action may require offsite disposal of contaminated material.	Relevant and Appropriate
DOT rules for Hazardous Materials Transport (49 CFR Parts 107, 171.1–500).	Response action may include offsite treatment and disposal.	Relevant and Appropriate
RCRA–Organic Air Emissions Standards for Process Vents (40 CFR 264 Subpart AA).	Response action may involve the release of contaminants to the air.	Applicable
Air Stripper Control Guidance (OSWER Directive 9355.0-28).	Response action may involve the release of contaminants to the air.	Applicable

Table 5-2. State of Virginia applicable or relevant and appropriate requirements

Requirements	Description	Category
Chemical-Specific		
Virginia Water Quality Standards (9 VAC 25-260-5 to 550).	Response action may involve discharge to surface waters. Treated effluent must meet the effluent limits in the AOC that are consistent with Virginia Water Quality Standards.	Applicable
Virginia Pollutant Discharge Elimination System Permit Regulation (9 VAC 25-31-10 to 940).	VPDES Permits are required for surface water discharges that are not directed through WWTP. This requirement will be applicable if it is determined that surface water no longer requires treatment.	Applicable
Virginia Regulations for the Control and Abatement of Air Pollution (9 VAC 5).		
Virginia Ambient Air Quality Standards (9 VAC 5-30-10 to 80).	Response action is required to comply with air quality standards for particulate matter.	Applicable
Virginia Standards of Performance for Visible Emissions and Fugitive Dust/Emissions [Rule 5-1]	Response action is required to comply with visible emission and fugitive dust emission standards.	Applicable
Virginia Standards of Performance for Toxic Pollutants [Rule 5-3] (9 VAC 5-50-160 to 230).	Response action is required to comply with the performance standards for any emission of a toxic air pollutant.	Applicable
Location-Specific		
Virginia Wetlands Regulations and Virginia Wetlands Mitigation Compensation Policy (2 VAC 20-390-10 to 50).	Pertains to wetlands identified on site for the protection of general ecological concerns.	Relevant and Appropriate
Virginia Floodplain Management Program and Virginia General Provisions Relating to Marine Resources Commission (Va. Code Ann. Sections 28.2-1300 to 1320).	Relates to construction activities on the 100-year floodplain. A portion of the response action may take place in the 100-year floodplain.	Relevant and Appropriate
Action-Specific		
Virginia solid Waste Management Regulations (VSWMR) (9 VAC 20-80-10-780).		
9 VAC 20-80-10 and 9 VAC 200D).	Definitions and requirements that justify closure inplace.	Applicable
9 VAC 20-80-170 through 230 (Open Dumps).	Standards and monitoring requirements for groundwater associated with closure of the basins.	Relevant and Appropriate
9 VAC 20-80-270 (Industrial Waste Disposal Facilities).	The regulations provide the closure and post-closure requirements for industrial waste disposal facilities that are relevant to the closure of viscose basins 9, 10, and 11.	Relevant and Appropriate
9 VAC 20-80-380 (Surface Impoundments and Lagoons).	Additional standards relevant to the closing of viscose basins 9, 10, and 11.	Relevant and Appropriate
Virginia Erosion and Sediment Control Regulations (4 VAC 50-30-10 to 110).	Soil disturbances are required to comply with erosion and sedimentation control regulations.	Applicable
Virginia Stormwater Management Regulations (4 VAC 3-20-10 to 251).	Stormwater will need to be managed for all activities that disturb more than one acre of land.	Applicable

Table 5-3. Summary of remediation technologies evaluated to date for viscose sludge at the Avtex Site

Technology	Description	Comments
Particle size reduction	Mechanical grinding to improve handling characteristics.	High-speed sheering is capable of reducing the particle size and enhancing chemical solubilization of the sludge.
Hydraulic containment	Extraction and ex-situ treatment of affected groundwater.	Effective means of controlling continued loading of CS_2 to groundwater. Requires long-term operation and maintenance.
Capping	Placement of a low-permeability cap over the basins to prevent infiltration of meteoric water.	Effectiveness uncertain. May require structural support due to low load-bearing capacity of the sludge.
In-situ bottom grouting	Injection of solidifying agents to the basin bottom to form a barrier to contaminant loading to groundwater.	Effectiveness uncertain. High cost.
Soil washing	Flushing excavated sludge with water to remove contaminants.	Removal of carbon disulfide was inconclusive during laboratory testing.
Chemical addition	Addition of chemicals to remove, destroy, or stabilize the contaminant.	Strong acid or base addition at elevated temperature was shown to be effective at solubilizing the sludge. CS_2 removal was not evaluated.
Solidification/ stabilization	Addition of pozzolanic chemicals (e.g., cement) to form a stabilized mass.	Ineffective at producing a stable material.
Drying	Ambient air or heated drying to remove moisture.	Field evidence indicates that drying may be effective at removing CS_2. Heating increased chemical solubilization rates. Sludge forms a brittle mass when dried.
Composting	Conventional aerobic composting.	Thought to have limited effectiveness due to the difficulty associated with establishing aerobic conditions throughout the sludge material.
Advanced fluidized composting (AFC)	Aerobic biodegradation of the sludge in an above-ground reactor.	Shown to be highly effective at reducing sludge mass and volume. Likely effective at reducing CS_2, although removal mechanism unknown. Requires excavation and physical and chemical pretreatment of the sludge.
Vermiculture	In-situ biodegradation of the sludge by application of worms.	Worms are effective at consuming the sludge and may produce a salable end product. CS_2 removal not clearly demonstrated, and removal mechanism unknown. Some initial excavation required. Dewatering required.
Six-phase electrical resistance soil heating	In-situ application of electrical current to heat the viscose and volatilize CS_2 for vapor recovery.	Vapor recovery may be difficult. Preliminary analysis suggests that the technology is cost prohibitive.

Table 5-4. Site characterization data gaps

General Data Gap	Identifier	Specific Data Gap
Confirm the nature and extent of groundwater contamination.	DG1	Define the extent of offsite migration of site chemicals in groundwater.
	DG2	Establish current distribution of site chemicals in groundwater.
Refine the understanding of identified source areas and evaluate potential additional source areas.	DG3	Evaluate the extent to which viscose basins 9, 10, and 11 are an ongoing source of chemicals to groundwater.
	DG4	Evaluate the potential release of contaminants from plant-area facilities to underlying groundwater.
	DG5	Evaluate whether viscose basins 1–8 are an ongoing source of site chemicals to groundwater.
Refine the understanding of the offsite migration of groundwater chemicals.	DG6	Quantify DAPL density to evaluate gravitational influences on offsite chemical migration.
	DG7	Define the bedrock aquifer potentiometric surface west of the South Fork of the Shenandoah River to evaluate hydraulic head influences on offsite chemical migration.
	DG8	Identify residential wells that potentially may be affected by future offsite chemical migration.

AR302254

Table 5-5a. Remedial action-specific data gaps for selected in-situ remedial actions for viscose basins 9, 10, and 11

Remedial Action	Description	Data Gap: Basin Hydrology	Data Gap: Waste Viscose Physical/Chemical Properties	Data Gap: Pore-Water Chemistry	Data Gap: Remedial Effectiveness
Containment Options					
Hydraulic control of leachate	Use of pumping wells to prevent leachate from migrating from basins.	BH1 Evaluate feasibility of basin dewatering. BH2 Quantify the basin water balance.	Existing data are sufficient.	C1 Evaluate potential for well and/or pump fouling.	Existing data are sufficient.
Cap	Use of a soil or impermeable cap to reduce or prevent infiltration of water to the basins.	BH2 Quantify the basin water balance.	V1 Evaluate the stability and long-term integrity of a cap.	Existing data are sufficient.	R1 Quantify the hydrolysis rate for carbon disulfide in the basins.
Cap with vertical barriers	Use of a cap plus impermeable vertical barriers to prevent the flow of water to and from the basins.	BH2 Quantify the basin water balance.	V1 Evaluate the stability and long-term integrity of a cap.	Existing data are sufficient.	R1 Quantify the hydrolysis rate for carbon disulfide in the basins.
Cap with hydraulic control	Use of a cap and pumping to prevent the flow of water into, and leachate from, the basins.	BH1 Evaluate feasibility of basin dewatering. BH2 Quantify the basin water balance.	V1 Evaluate the stability and long-term integrity of a cap.	C1 Evaluate potential for well and/or pump fouling.	R1 Quantify the hydrolysis rate for carbon disulfide in the basins.
Cap with hydraulic control and vertical barriers	Use of a cap, pumping, and vertical barriers to prevent the flow of water into, and leachate from, the basins.	BH1 Evaluate the feasibility of basin dewatering. BH2 Quantify the basin water balance.	V1 Evaluate the stability and long-term integrity of a cap.	C1 Evaluate potential for well and/or pump fouling.	R1 Quantify the hydrolysis rate for carbon disulfide in the basins.
Cap with vertical barriers, and bottom grouting	Entombment of the basins to prevent the flow of water into, and leachate from, the basins.	BH2 Quantify the basin water balance.	V1 Evaluate the stability and long-term integrity of the cap.	Existing data are sufficient.	R2 Evaluate the feasibility of bottom grouting the basins.
Biological Options					
Vermiculture	In-situ use of worms to consume the viscose waste, and excavation and sale of resulting castings.	BH1 Evaluate the feasibility of basin dewatering. BH2 Quantify the basin water balance.	V2 Quantify the range of chemical and physical properties that may limit worm viability.[a]	C2 Quantify the range of chemical properties that may limit worm viability.[a]	R3 Evaluate fate of site chemicals, carbon disulfide removal efficiency, and quality and economic viability of the castings.[a]

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Table 5-5a. (cont.)

Remedial Action	Description	Data Gap: Basin Hydrology	Data Gap: Waste Viscose Physical/Chemical Properties	Data Gap: Pore-Water Chemistry	Data Gap: Remedial Effectiveness
Chemical Options					
Oxidation	Use of a chemical oxidant to degrade the waste.	Existing data are sufficient.	V3 Quantify the oxidative demand of the viscose waste.	C3 Quantify the oxidative demand of the basin pore water.	R4 Identify potential chemical additives and quantify carbon disulfide removal efficiency.
Chemical Grouting	Use of a chemical to reduce the permeability and/or chemical leachability of the waste.	Existing data are sufficient.	Existing data are sufficient.	C4 Identify chemical properties that may affect treatment efficiency.	R5 Identify potential chemical additives and quantify reduction in leachability.
Surface application of chemicals	Application of a chemical to the surface of the basins to reduce infiltration and/or chemically degrade the waste.	BH3 Evaluate the feasibility of achieving sufficient chemical dispersal. BH2 Quantify the basin water balance.	V4 Quantify the range of chemical and physical properties that may limit treatment efficiency.	C4 Identify chemical properties that may affect treatment efficiency.	R6 Identify potential chemical additives and quantify site chemicals attenuation/degradation.
Solidification/ Stabilization	Application of a chemical(s) to solidify or stabilize the waste.	Existing data are sufficient.	V4 Quantify the range of chemical and physical properties that may limit treatment efficiency.	C4 Identify chemical properties that may affect treatment efficiency.	R5 Identify potential chemical additives and quantify reduction in leachability.
Electrical/Thermal Options					
Direct Electrical Resistance Heating	Application of electrical current to heat the waste viscose and volatilize carbon disulfide and water.	Existing data are sufficient.	V5 Evaluate the electrical conductivity of the waste viscose.	C5 Evaluate the electrical conductivity of the basin pore water.	R7 Quantify carbon disulfide removal efficiency.

[a] Data gaps based on the findings of Exponent 1998.

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Table 5-5b. Remedial action-specific data gaps for selected ex-situ remedial actions for viscose basins 9, 10, and 11

Remediation Action	Description	Data Need: Basin Hydrology	Data Need: Waste Viscose Physical/Chemical Properties	Data Need: Pore-Water Chemistry	Data Need: Remedial Effectiveness
Excavation Options					
Conventional Excavation	Use of conventional construction and/or dredging equipment to remove the waste from the basins.	BH1 Evaluate the need for, and feasibility of, basin dewatering. BH2 Estimate the volume of dewater that will require treatment.	V1 Evaluate the structural stability of the waste viscose and the need for shoring or other provisions.	C1 Characterize the pore-water chemistry to identify potential worker exposure hazards. C2 Characterize chemistry to select appropriate treatment technology for excavated dewater.	R1 Evaluate the feasibility of using conventional machinery to remove waste viscose from the basins.
Non-Conventional Excavation	Use of non-conventional equipment to remove the waste from the basins.	Existing data are sufficient.	Existing data are sufficient.	Existing data are sufficient.	R2 Identify potential equipment and efficacy, including the possible use of mining/tunneling equipment.
Freeze and Fracture	Use of freezing agent to freeze the waste viscose to allow for fracturing and ease excavation.	Existing data are sufficient.	V2 Evaluate the response of waste viscose to different freezing agents.	Existing data are sufficient.	R3 Evaluate feasibility of freezing and fracturing the waste viscose.
Pre-Treatment (Materials Handling) Options[a]					
Solubilization[b]	Use of heat, acid, or other solubilizing agent to change the waste matrix to a liquid form.	Not applicable	Existing data are sufficient.	Existing data are sufficient.	R4 Evaluate the efficiency of chemical and physical solubilization techniques.
Particle Size Reduction	Use of grinder or chipper to reduce the particle size of the waste viscose.	Not applicable	V3 Evaluate the amenability of the waste viscose to shearing.	Existing data are sufficient.	R5 Identify potential equipment and evaluate efficiency.

AR302257

Table 5-5b. (cont.)

Remediation Action	Description	Data Need: Basin Hydrology	Waste Viscose Physical/Chemical Properties	Pore-Water Chemistry	Remedial Effectiveness
Pre-Treatment (Materials Handling) Options[a] (cont.)					
Solidification/ Stabilization[b]	Use of a stabilizing agent to improve the materials handling properties of the waste.	Not applicable	Existing data are sufficient.	Existing data are sufficient.	R6 Evaluate the efficiency of chemical and physical solidification/stabilization techniques.
Mechanical Dewatering	Use of a filter press or centrifuge to dewater the excavated viscose.	Not applicable	V4 Evaluate the amenability of the waste viscose to mechanical dewatering.	Existing data are sufficient.	R7 Identify potential equipment and evaluate carbon disulfide removal.
Drying	Use of drying beds to reduce the water content of the sludge and to volatilize VOCs.	Not applicable	V5 Evaluate the amenability of the waste viscose to drying.	Existing data are sufficient.	R8 Evaluate carbon disulfide removal.
Biological Treatment Options[c]					
Vermiculture	Use of worms to consume the viscose waste excavated from the basins.	Not applicable	V6 Quantify the range of chemical and physical properties that may limit worm viability.	C3 Quantify the range of chemical properties that may limit worm viability.	R9 Evaluate fate of site chemicals, carbon disulfide removal efficiency, and quality and economic viability of castings.
Activated Sludge (requires pretreatment)	Treatment of the waste viscose excavated from the basins at the site's WWTP.	Not applicable	V7 Evaluate feasibility of treating waste viscose using the site WWTP.	Not applicable	R10 Evaluate fate of site chemicals following treatment.

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Table 5-5b. (cont.)

Remedial Action	Description	Data Need: Basin Hydrology	Data Need: Waste Viscose Physical/Chemical Properties	Data Need: Pore-Water Chemistry	Data Need: Remedial Effectiveness
Biological Treatment Options[c] (cont.)					
Advanced Fluidized Bed Composting (requires pretreatment)	Composting of the excavated waste viscose to remove VOCs and reduce the volume of solids.	Not applicable	Existing data are sufficient.	Existing data are sufficient.	R11 Evaluate fate of site chemicals following treatment.
Bioremediation (requires pretreatment)	Landfarming excavated waste viscose to stimulate biodegradation.	Not applicable	Existing data are sufficient.	Existing data are sufficient.	R12 Evaluate fate of site chemicals following treatment.
Chemical and Thermal Treatment Options[c]					
Oxidation	Use of an oxidant to degrade the excavated waste viscose.	Not applicable	V8 Quantify the oxidative demand of the viscose waste.	C4 Quantify the oxidative demand of the basin pore water.	R13 Identify potential chemical additives and quantify carbon disulfide removal.
Solidification/ Stabilization	Chemical addition to excavated waste viscose to reduce the chemical leachability.	Not applicable	Existing data are sufficient.	Existing data are sufficient.	R14 Evaluate the feasibility and long-term effectiveness of solidification/stabilization.
Incineration	Thermal destruction of the excavated waste viscose.	Not applicable	Existing data are sufficient.	Existing data are sufficient.	R15 Evaluate the feasibility of incineration and the fate of site chemicals following treatment.

[a] It is possible that excavated waste viscose will require pre-treatment prior to final treatment by an ex-situ process(es).

[b] These techniques may be used both in situ or ex situ to improve the handling characteristics of the waste.

[c] All of the ex-situ treatment processes require that the waste first be removed from the basins (e.g., by excavation), and many require that the waste undergo pretreatment.

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Table 5-6. Remedial action-specific data gaps for selected groundwater remedial actions

Remedial Action	Description	Data Gap							
		Plume Morphology		Aquifer Hydrology		Groundwater Chemistry		Remedial Effectiveness	
Groundwater extraction and ex-situ treatment: *Reduce chemical mass in groundwater*	Use of pumping wells to remove contaminated groundwater from the bedrock aquifer.	P1	Refine understanding of plume morphology and extent of contamination.	H1	Characterize offsite groundwater and DAPL flow pathways.	C1	Evaluate the potential for well/pump fouling.	R1	Identify appropriate treatment technology(s) and disposal options for extracted groundwater.
Groundwater extraction and ex-situ treatment: *Prevent migration of site chemicals*	Use of pumping wells to prevent the migration of groundwater contaminants to offsite drinking water wells.	P1	Refine understanding of plume morphology, targeting the plume leading edge.	H1	Characterize offsite groundwater and DAPL flow pathways.	C1	Evaluate the potential for well/pump fouling.	R1	Identify appropriate treatment technology(s) and disposal options for extracted groundwater.
In-situ air sparging or bioventing	Use of air-injection to volatilize and/or induce aerobic biodegration of organic contaminants.	P1	Refine understanding of plume morphology and extent of contamination.		No additional data needed.	C1	Evaluate the potential for well fouling.	R2	Evaluate effectiveness of technology at attenuating or degrading site chemicals.
Chemical injection: *Immobilize or degrade site chemicals.*	Injection of chemicals to induce or enhance the chemical immobilization or degradation of contaminants.	P1	Refine understanding of plume morphology and extent of contamination.		No additional data needed.	C1	Evaluate the potential for well/pump fouling.	R3	Identify chemicals for injection and evaluate their effectiveness at attenuating or degrading site chemicals.
								R4	Evaluate the potential use of hydrogen peroxide to enhance carbon disulfide hydrolysis.
	Injection of chemicals to induce chemical precipitation in the bedrock aquifer and reduce permeability.	P1	Refine understanding of plume morphology and extent of contamination.		No additional data needed.	C1	Evaluate the potential for well/pump fouling.	R5	Identify chemicals for injection and evaluate effectiveness at reducing bedrock aquifer permeability.

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Table 5-6 (cont.).

Remedial Action	Description	Data Gap							
		Plume Morphology		Aquifer Hydrology		Groundwater Chemistry		Remedial Effectiveness	
Monitored natural attenuation and institutional controls	Monitor the plume and natural attenuation of contaminants. Apply institutional controls to prevent use of contaminated groundwater.	P1	Refine understanding of plume morphology, targeting the plume's leading edge.	H1	Characterize offsite groundwater and DAPL flow pathways.	C2	Characterize water quality parameters (e.g., pH, TDS) that affect natural attenuation of site chemicals.	R6 R7 R8	Quantify carbon disulfide hydrolysis rates. Quantify the natural chemical attenuation of metals. Identify residential wells that potentially would be affected by further plume migration.

AR302261

Table 5-7. Approach to addressing site characterization data gaps

Identifier	Description	Approach to Addressing Data Gap
DG1	Define the extent (leading edge) of offsite migration of site chemicals in groundwater.	Quantify site chemical concentrations in wells 115/215/315 to determine if these wells currently represent the leading edge of the plume. If site chemical concentrations are greater than EPA Region III human health risk-based criteria, install well 343 downstrike to characterize extent of groundwater contamination.
DG2	Establish current distribution of site chemicals in groundwater.	Collect groundwater samples from newly installed wells, selected existing wells, and Geoprobe wellpoints to quantify groundwater chemical concentrations.
DG3	Evaluate the extent to which viscose basins 9, 10, and 11 are an ongoing source of chemicals to groundwater.	Quantify the mass of free and bound carbon disulfide in samples of waste viscose through the use of specially designed sample digestion techniques. Conduct laboratory study to estimate the potential for long-term release of hydroxide from viscose basins 9, 10, and 11 to groundwater. Quantify the viscose-basin water balance to estimate the percolation rate of basin leachate to groundwater.
DG4	Evaluate the potential release of contaminants from plant-area facilities to underlying groundwater.	Install and sample groundwater monitoring wells 128, 129, 130 and 131, and Geoprobe well points GP1–14 downgradient of the plant area. Install well 001and 002, collocated with the well triplets 101/201/301 and 102/202/302, respectively, to evaluate background overburden groundwater quality.
DG5	Evaluate whether viscose basins 1–8 are an ongoing source of site chemicals to groundwater.	Install and sample shallow and intermediate bedrock wells (132/232) upgradient of viscose basins 9–11 and downgradient of viscose basins 1–8.
DG6	Quantify DAPL density to evaluate gravitational influences on offsite chemical migration.	Collect plume water samples from selected wells and measure the density of the plume water.
DG7	Define the bedrock aquifer potentiometric surface west of the Shenandoah River to evaluate hydraulic head influences on offsite chemical migration.	Review permits for any available data on residential wells west of the South Fork of the Shenandoah River and record first-water level data. If private wells are used to obtain water levels, well owners may be interviewed to obtain any additional data available (e.g. lithology, well depth, ect.). To the extent possible, this information will be verified in the field.
DG8	Identify residential wells that potentially may be affected by future offsite chemical migration.	Perform a well survey to identify any additional wells that may have been installed west of the South Fork of the Shenandoah River since 1987--the date of the most recent well survey.

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Table 5-8a. Approach to addressing remedial action-specific data needs for in-situ remedial alternatives for viscose basins 9, 10, and 11

Identifier	Data Need	General Approach Category			
		Literature and/or Industry Review	Collect Additional Site-Specific Data	Calculations and/or Modeling	Laboratory Tests
Basin Hydrology					
BH1	Evaluate the feasibility of basin dewatering.	None	Perform single-well pumping tests in selected basin wellpoints.	Perform calculations to estimate dewatering yields based on results of the field study.	None
BH2	Quantify the basin water balance.	None	Perform field infiltrometer test. Quantify physical properties of the waste viscose (e.g., wilting point, field capacity, porosity, bulk density, moisture content).	Perform HELP modeling to quantify infiltration rates. Perform MODFLOW modeling to evaluate interaction between basins and overburden groundwater.	None
BH3	Evaluate the feasibility of achieving sufficient chemical dispersal following surface application.	None	Record viscose consistency during wellpoint installation.	None	None
Physical/Chemical Properties of Waste Viscose					
V1	Evaluate the stability and long-term integrity of a cap.	None	Conduct geotechnical tests on the waste viscose.	Perform calculations to estimate the ability of the viscose to support a cap.	None
V2	Vermiculture: quantify the range of chemical and physical properties that may limit worm viability.	None	Quantify waste viscose pH, salinity, and site chemical concentrations.	None	None
V3	Quantify the oxidative demand of the viscose sludge.	None	Measure the chemical oxygen demand of the waste viscose.	None	Perform laboratory tests to quantify the amount of oxidant required to treat a sample of waste viscose.

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Table 5-8a. (cont.)

Identifier	Data Need	General Approach Category: Literature and/or Industry Review	Collect Additional Site-Specific Data	Calculations and/or Modeling	Laboratory Tests
Physical/Chemical Properties of Waste Viscose (cont.)					
V4	Quantify the chemical and physical properties that may limit treatment efficiency.	None	Record waste consistency during wellpoint installation. Quantify waste viscose pH, salinity, and site chemical concentrations.	None	None
V5	Evaluate the electrical conductivity of the waste viscose.	None	None	None	Perform laboratory study of waste viscose conductivity.
Pore-water chemistry					
C1	Evaluate the potential for well and/or pump fouling.	Review literature and industry data to identify conditions likely to lead to fouling.	Quantify silica, aluminum, iron, pH, and other groundwater parameters to evaluate potential for well and/or pump fouling.	Perform geochemical modeling to identify potential precipitates that may lead to fouling.	None
C2	Quantify the range of chemical and physical properties that may limit worm viability.	None	Quantify waste viscose pH, salinity, and site chemical concentrations.	None	None
C3	Quantify the oxidative demand of the basin pore-water.	None	Measure the chemical oxygen demand of the basin pore water.	None	None
C4	Identify the chemical properties that may affect efficiency of chemical-based treatment approaches.	None	Quantify silica, aluminum, iron, major ions, redox, and pH in basin pore water.	Perform geochemical modeling to identify potential beneficial in-situ reactions (e.g. precipitation).	None
C5	Evaluate the electrical conductivity of the basin pore water.	None	None	None	Perform laboratory study to measure the electrical resistance of the basin pore water.

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Table 5-8a. (cont.)

Identifier	Data Need	General Approach Category			
		Literature and/or Industry Review	Collect Additional Site-Specific Data	Calculations and/or Modeling	Laboratory Tests
Remedial Effectiveness					
R1	Quantify the hydrolysis rate of carbon disulfide in the basin pore waters.	Review literature.	None	None	None
R2	Evaluate the feasibility of bottom grouting the viscose basins.	Review literature.	None	Perform geochemical modeling to identify potential grouts that can be formed.	None
R3	Vermiculture: evaluate the fate of site chemicals, treatment efficiency, and quality and economic viability of castings.	Review data on the castings industry.	None	Estimate the potential revenue that may be generated by the sale of castings.	Perform laboratory study of worm viability in waste viscose, and composition of resulting castings.
R4	Identify potential oxidants and quantify their treatment efficiency for removing carbon disulfide from waste viscose.	Review literature.	None	None	Perform laboratory study of selected oxidants.
R5	Identify potential chemical additives and quantify reduction in leachability.	Review literature.	Quantify silica, aluminum, iron, major ions, and pH in basin pore water.	Perform geochemical modeling to identify potential grouts or precipitates that can be formed.	None
R6	Identify potential chemicals that can be applied to the surface of the basins and quantify attenuation/ degradation.	Review literature.	Quantify silica, aluminum, iron, major ions, and pH in basin pore water.	Perform geochemical modeling.	None
R7	Quantify the carbon disulfide removal efficiency of direct electrical resistance heating.	Review case studies.	Quantify electrical properties of the waste viscose and the basin pore waters.	Modeling and calculations based on the results of the laboratory tests to evaluate feasibility of electrical heating.	Laboratory study.

AR302295

Table 5-8b. Approach to addressing remedial action-specific data gaps for ex-situ remediation alternatives for viscose basins 9, 10, and 11

Identifier	Data Gap	General Approach Category			
		Literature and/or Industry Review	Collect Additional Site-Specific Data	Calculation and/or Modeling	Laboratory Tests
Basin Hydrology					
BH1	Evaluate the need for, and feasibility of, basin dewatering during excavation.	Contact experts in the construction industry.	Excavate waste viscose during field treatability testing.	None	None
BH2	Estimate the volume of dewater produced during excavation.	None	Perform single-well pumping tests in viscose basin wellpoints.	Perform calculations to estimate the volume of dewater produced during excavation.	None
Physical/Chemical Properties of Waste Viscose					
V1	Evaluate the structural stability of the waste viscose during excavation.	Contact experts in the construction industry.	Excavate waste viscose during field treatability testing.	None	None
V2	Evaluate the response of waste viscose to different freezing agents.	Review literature to identify potential freezing agents and application technologies.	None	None	Perform laboratory tests to evaluate various freezing agents.
V3	Evaluate the amenability of the waste viscose to shearing.	Contact vendors of shearing machinery.	None	None	Perform laboratory shearing tests.
V4	Evaluate the amenability of the waste viscose to mechanical dewatering.	Contact vendors of dewatering machinery.	Perform single-well pumping tests in viscose basin wellpoints.	None	Perform laboratory dewatering tests.
V5	Evaluate the amenability of the waste viscose to drying.	None	None	None	Perform laboratory drying tests.
V6	Vermiculture: quantify the range of chemical and physical properties that may limit worm viability.	None	Quantify waste viscose pH, salinity, and COPC concentrations.	None	None

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Table 5-8b. (cont.)

Identifier	Data Gap	General Approach Category			
		Literature and/or Industry Review	Collect Additional Site-Specific Data	Calculation and/or Modeling	Laboratory Tests
Physical/Chemical Properties of Waste Viscose (cont.)					
V7	Evaluate the feasibility of treating the waste viscose at the site WWTP.	Contact personnel at operating viscose rayon plants that process waste viscose through their WWTPs.	None	None	None
V8	Quantify the oxidative demand of the waste viscose.	None	None	None	Perform laboratory chemical oxidation tests.
Pore-water chemistry					
C1	Characterize the pore-water chemistry to identify potential worker exposure hazards.	None	Quantify the concentrations of potentially hazardous chemicals in the basin pore water.	Calculate the potential worker exposure during excavation and treatment.	None
C2	Characterize chemistry to select an appropriate treatment technology for water resulting from excavation of the waste viscose.	Review literature and industry data to identify parameters necessary to evaluate various treatment technologies.	Perform major ion analyses on samples of basin pore water.	Perform modeling or calculations to estimate likely treatment efficiency.	None
C3	Vermiculture: quantify the range of chemical properties that may limit worm viability.	None	Quantify waste viscose pH, salinity, and COPC concentrations.	None	None
C4	Quantify the oxidative demand of the basin pore water.	None	Quantify the chemical oxygen demand (COD) of the basin pore water.	None	None
Remedial Effectiveness					
R1	Evaluate the feasibility of using conventional machinery to remove waste viscose from the basins.	Contact experts in the construction industry.	Excavate waste viscose during field treatability testing.	None	None

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Table 5-8b. (cont.)

Identifier	Data Gap	General Approach Category			
		Literature and/or Industry Review	Collect Additional Site-Specific Data	Calculation and/or Modeling	Laboratory Tests
Remedial Effectiveness (cont.)					
R2	Identify potential non-conventional equipment that could be used for removal of the waste viscose from the basins.	Contact experts in the construction, mining, and tunneling industries.	None	None	None
R3	Evaluate the feasibility of freezing and fracturing the waste viscose as a means of easing the excavation process.	Review literature and available industry case studies.	None	Calculate the freezing agent requirements.	Perform laboratory tests to evaluate the feasibility of freezing the waste viscose.
R4	Evaluate the efficiency of chemical and physical solubilization techniques.	Review available literature and bench-scale studies.	None	None	Perform laboratory tests to evaluate various solubilization techniques.
R5	Identify potential equipment that may be used to reduce the particle size of the waste viscose.	Contact experts in the construction industry.	None	None	Perform laboratory shearing test.
R6	Evaluate the efficiency of solidification/stabilization techniques to improve waste handling characteristics.	Review literature and previous site investigations.	None	None	Perform laboratory study.
R7	Identify potential equipment that may be used to mechanically dewater the waste viscose.	Contact vendors of dewatering machinery.	None	None	Perform laboratory dewatering tests.
R8	Evaluate the efficiency of drying the waste viscose as a treatment technology.	None	None	None	Perform laboratory study.

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Table 5-8b. (cont.)

Identifier	Data Gap	General Approach Category			
		Literature and/or Industry Review	Collect Additional Site-Specific Data	Calculation and/or Modeling	Laboratory Tests
Remedial Effectiveness (cont.)					
R9	Vermiculture: evaluate the fate of site chemicals, treatment efficiency, and quality and economic viability of castings.	Contact experts in the soil nutrient amendment industry and establish the economic viability and required quality parameters of worm castings.	None	Estimate the potential revenue that may be generated by the sale of castings.	Perform laboratory study.
R10	Evaluate the fate of site chemicals following treatment by the WWTP.	Review site records for the WWTP. Contact personnel at operating viscose rayon plants that process waste viscose through their WWTP.	None	None	None
R11	Evaluate the fate of site chemicals following treatment by advanced fluidized bed composting (AFC).	Review site records of laboratory testing of AFC treatment of the waste viscose.	None	None	None
R12	Evaluate the fate of site chemicals following landfarm-bioremediation treatment.	Review literature and case studies.	None	None	None
R13	Identify potential oxidants and quantify their treatment efficiency for waste viscose.	Review site records of laboratory testing of chemical oxidation of the waste viscose.	None	None	Perform laboratory study to evaluate the efficacy of various chemical oxidants.
R14	Evaluate the feasibility and effectiveness of solidification/stabilization as a permanent remedy.	Review site records of laboratory testing of solidification/stabilization of the waste viscose.	None	None	None
R15	Evaluate the feasibility of incineration and the fate of site chemicals following treatment.	Contact vendors of incineration technology.	None	None	None

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Table 5-9. Approach to addressing remedial alternative-specific data needs for groundwater

Identifier	Data Need	Literature and/or Industry Review	Collect Additional Site-Specific Data	Calculation and/or Modeling	Laboratory Tests
Plume Morphology					
P1	Refine the understanding of plume morphology and extent of contamination.	None	Characterize groundwater quality in newly installed and selected existing groundwater monitoring wells at the site.	None	None
Aquifer Hydrology					
H1	Characterize offsite groundwater and DAPL flow paths.	Perform a well survey for the area west of the river and compile available water-level data.	None	None	None
Groundwater Chemistry					
C1	Evaluate the potential for well and/or pump fouling during extraction and/or chemical or air injection.	Review literature and industry data to identify conditions likely to lead to fouling at the site.	Quantify silica, aluminum, iron, pH, and other groundwater parameters to evaluate potential for well fouling.	Perform geochemical modeling to identify potential precipitates that may lead to fouling.	None
C2	Identify the range of conditions that may affect attenuation or degradation of site chemicals.	None	None	Perform calculations to evaluate chemical attenuation/degradation under natural and various remedial conditions.	Laboratory tests to quantify carbon disulfide hydrolysis and metals attenuation under existing and remedial conditions.
Remedial Effectiveness					
R1	Identify appropriate treatment technologies for extracted groundwater.	Review literature and industry data to identify capabilities and limitations of various treatment technologies.	Perform major ion analyses on selected groundwater samples from the plume.	Perform modeling or calculations to estimate likely treatment efficiency.	None
R2	Evaluate effectiveness of air sparging and bioventing, and the fate of site chemicals following treatment.	Review literature and industry data.	None	Perform modeling or calculations to estimate stripping efficiency.	None

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Table 5-9. (cont.)

Identifier	Data Need	Literature and/or Industry Review	Collect Additional Site-Specific Data	Calculation and/or Modeling	Laboratory Tests
Remedial Effectiveness (cont.)					
R3	Identify potential chemicals for injection, and evaluate effectiveness.	Review literature and industry data.	Perform major ion analyses on selected groundwater samples from the plume.	Perform geochemical modeling to identify potentially effective chemicals for injection.	None
R4	Evaluate the potential use of hydrogen peroxide to enhance carbon disulfide hydrolysis.	Review literature.	None	None	Perform laboratory study to quantify carbon disulfide hydrolysis in the presence of hydrogen peroxide.
R5	Identify chemicals for injection and evaluate effectiveness of reducing bedrock aquifer permeability.	Review literature.	Perform major ion analyses on selected groundwater samples from the plume.	Perform geochemical modeling to identify potentially effective chemicals for injection.	None
R6	Quantify carbon disulfide hydrolysis rate.	Review literature.	None	Develop numerical model that predicts carbon disulfide hydrolysis rates.	None.
R7	Quantify metal natural attenuation.	Review literature.	Perform major ion analyses on selected groundwater samples from the plume to identify potential mineral solubility controls on metals concentrations.	Perform geochemical modeling to identify mineral solubility controls on metals concentrations. Perform calculations to estimate hydrogen sulfide production rate during carbon disulfide hydrolysis.	None
R8	Identify residential wells that potentially could be affected by further plume migration.	Perform well survey.	None	None	None

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Table 6-1. Summary of supplemental field and laboratory investigations to be conducted under phased scope of work

Phase I	Phase II	Phase III
Install monitoring wells (Sections 6.2.1.3 and 6.2.1.4)	Install boreholes and wellpoints in and adjacent to viscose basins 9, 10, and 11 (Sections 6.2.1.1 and 6.2.1.2)	Field treatability testing (Section 6.4)
Install Geoprobe® wellpoints (Section 6.2.1.5)	Install and sample additional deep monitoring well(s) if necessary (Sections 6.2.1.4)	
Groundwater sampling and analysis (Section 6.2.2)	Pore-water sampling and analysis in viscose basins 9, 10, and 11 (Section 6.2.2)	
Residential well survey (Section 6.2.5)	Infiltration rate testing (Section 6.2.4.3)	
	Single well pumping tests (Section 6.2.4.2)	
	Site-wide measurement of groundwater levels (Section 6.2.4.1)	
	Collection of waste viscose for laboratory testing (Section 6.2.1.1)	
	Laboratory testing of waste viscose (Section 6.2.6)	
	Geologic mapping (section 6.2.7)	
	Laboratory treatability testing (Section 6.3)	

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Table 6-2. Waste viscose and soil sample collection summary for viscose basin boreholes

Test Type	Sampling Method[a]	Sample Dimensions	Number of Basins	Locations per Basin	Sample Depths: Unsaturated Zone 0–12"	Unsaturated Zone 12–24"	Unsaturated Zone Above Water Table	Saturated Zone Below Water Table	Saturated Zone Base of Viscose	Saturated Zone Top of Overburden	Total Samples	Lab[b]
Material/Geotechnical Properties												
Waste viscose hydrologic parameters[c]	SS Liner	2-in ID, 12-in long	3	2	x	x					12	GEO
Overburden vertical hydraulic conductivity	SS Liner	2-in ID, 12-in long	3	1						x	3	GEO
Consolidation/shear tests	Shelby Tube	3-in ID, 24-in long	3	1		x	x	x			9	GEO
Chemical Source Characterization												
Free and bound CS_2 analysis	SS Liner	2-in ID, 6-in long	3	1			x	x	x		9	CAS
Hydroxide liberation tests	SS Liner	2-in ID, 6-in long	3	1			x	x	x		9	EBL
Chemical analysis[d]	Splitspoon	2-in ID, 12-in long	3	2			x	x	x		18 + 1 dup[e]	CAS
Laboratory Treatability Testing												
Chemical oxidation tests	Composite	NA	3	3							9[f]	EBL
Vermiculture treatment tests	Composite	NA	3	3							9[f]	SWI
Direct electrical resistance heating tests	SS Liner	2-in ID, 12-in long	3	1		x	x	x			9	AHA
Handling improvement tests	Composite	NA	3	3							9[f]	EBL

Note: CS_2 - carbon disulfide
ID - inner diameter
NA - not applicable
SS - stainless steel

[a] All SS liners and shelby tube samples will be sealed with end caps and Teflon tape.

[b] Lab abbreviations are as follows:

AHA Applied Hydrology Associates, Inc.
CAS Columbia Analytical Laboratories, Inc.
EBL Exponent Boulder Lab
GEO GeoSyntec Consultants
SWI Smartworm, Inc.

[c] Viscose hydrologic parameters include field capacity, wilting point, vertical hydraulic conductivity, porosity, moisture content, and bulk density.

[d] Includes quantification of carbon disulfide, TAL inorganics, TCL VOCs, TCL SVOCs, chloride, silica, sulfate, paste pH, COD and percent solids

[e] At one selected location, an additional borehole, immediately adjacent to the initial borehole, will be installed to collect a duplicate sample for chemical analysis.

[f] Material collected from across the thickness of the waste viscose (excluding the crust layer).

AR302273

Table 6-3. Temporary wellpoint installation summary

Well ID	Unit Monitored	Location	Anticipated Total Depth (ft)	Monitored Interval Depth (ft)	Diameter (in)	Drilling Method	Purpose of Wellpoint
WP01	Viscose	Viscose basin 9	25	15–25	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP02	Viscose	Viscose basin 9	25	15–25	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP03	Viscose	Viscose basin 9	25	15–25	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP04	Viscose	Viscose basin 10	22	12–22	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP05	Viscose	Viscose basin 10	22	12–22	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP06	Viscose	Viscose basin 10	22	12–22	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP07	Viscose	Viscose basin 11	17	7–17	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP08	Viscose	Viscose basin 11	17	7–17	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP09	Viscose	Viscose basin 11	17	7–17	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP10	Overburden	North of viscose basin 11	25	15–25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
WP11	Overburden	East of viscose basin 11	25	15–25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
WP12	Overburden	East of viscose basin 10	25	15–25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
WP13	Overburden	South of viscose basin 10	25	15–25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
WP14	Overburden	Between viscose basins 9, 10, 11	25	15–25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
GP01	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP02	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP03	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant

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Table 6-3. (cont.)

Well ID	Unit Monitored	Location	Anticipated Total Depth (ft)	Monitored Interval Depth (ft)	Diameter (in)	Drilling Method	Purpose of Wellpoint
GP04	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP05	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP06	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP07	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP08	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP09	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP10	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP11	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP12	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP13	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP14	Overburden	Downgradient of Plant	25	20–25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant

Notes: Anticipated well depths and monitored intervals may vary based on field conditions.
ATV - all terrain vehicle

AR302275

Table 6-4. Monitoring well installation summary for OU-7

Well ID	Unit Monitored	Location	Anticipated Total Depth (ft)	Monitored Interval Depth (ft)	Diameter (inches)	Preferred Drilling Method	Purpose of Monitoring Well
001	Overburden	Near well cluster 101/201/301	25	15–25	2	Hollow stem auger or air rotary	Background overburden water quality
002	Overburden	Near well cluster 102/202/302	25	15–25	2	Hollow stem auger or air rotary	Background overburden water quality
128	Shallow bedrock	West of central portion of plant area	45	35–45	2	Air rotary/downhole air hammer	Water quality downgradient of plant area
129	Shallow bedrock	Southwest of plant area	45	35–45	2	Air rotary/downhole air hammer	Water quality downstrike and downgradient of plant area
130	Shallow bedrock	West of northern portion of plant area	45	35–45	2	Air rotary/downhole air hammer	Water quality downstrike and downgradient of plant area
131	Shallow bedrock	Southwest of boneyard	45	35–45	2	Air rotary/downhole air hammer	Water quality downstrike and downgradient of plant area / boneyard
132	Shallow bedrock	Downstrike of viscose basins 1–8 and new landfill, upstrike of viscose basins 9–11	45	35–45	2	Air rotary/downhole air hammer	Water quality downstrike and downgradient of viscose basins 1–8 / upstrike of viscose basins 9–11
232	Intermediate bedrock	Downstrike of viscose basins 1–8 and new landfill, upstrike of	140	120–140	2	Air rotary/downhole air hammer	Water quality downstrike and downgradient of viscose basins 1–8 / upstrike of viscose basins 9–11
343	Deep bedrock	Southwest of wells 115/215/315	330	TBDF	2	Air rotary/downhole air hammer	Downstrike extent of leading edge of dense carbon disulfide plume, installation contingent on Phase I sample results
			(target elevation = 290–300 ft msl)				

Notes: Anticipated well depths and monitored intervals may vary based on field conditions.
TBDF - to be determined in the field based on monitoring during drilling for indicators of plume (specific conductivity)

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Table 6-5. Well and wellpoints sampling and analysis plan

Well ID	Monitoring Depth Zone	Proposed or Existing	On-site/ Off-site	Analyses[a]	Rationale
001	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, PCBs, pest, and field meaurements	Background
002	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, PCBs, pest, and field meaurements	Background
004	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
005	Overburden	Existing	On-site	TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling
009	Overburden	Existing	On-site	TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling
011	Overburden	Existing	On-site	TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling
014	Overburden	Existing	On-site	TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling
017	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
021	Overburden	Existing	On-site	TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling
022	Overburden	Existing	On-site	TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling
024	Overburden	Existing	On-site	TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling
026	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
MW02	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Viscose basins
MW07	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
MW08	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10

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Table 6-5. (cont.)

Well ID	Monitoring Depth Zone	Proposed or Existing	On-site/ Off-site	Analyses[a]	Rationale
MW09	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, density, conventionals, and field	Viscose basins
MW10	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Viscose basins
MW11	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
MW12	Overburden	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics (filtered and unfiltered), ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
GP01	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP02	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP03	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP04	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP05	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP06	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP07	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP08	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP09	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP10	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP11	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant

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Table 6-5. (cont.)

Well ID	Monitoring Depth Zone	Proposed or Existing	On-site/ Off-site	Analyses[a]	Rationale
GP12	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP13	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
GP14	Overburden	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Characterize water quality downgradient of plant
101	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, density, conventionals, and field meaurements	Background
102	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, PCBs, pest, and field meaurements	Background
103	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Plant area
104	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
105	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, and field meaurements	Plume
111	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Downstrike of plant area
112	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Downstrike of plant area
114	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery
115	Shallow bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, and field meaurements	Plume leading edge
116	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, lab, and field	Plume
117	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
118	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
119	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, and field meaurements	Background, confirmation sampling

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Table 6-5. (cont.)

Well ID	Monitoring Depth Zone	Proposed or Existing	On-site/ Off-site	Analyses[a]	Rationale
120	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
128	Shallow bedrock	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Plant area
129	Shallow bedrock	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Plant area
130	Shallow bedrock	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, density, conventionals, and field meaurements	Plant area
131	Shallow bedrock	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Plant area
132	Shallow bedrock	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, and field meaurements	Viscose basins 1–8
137	Shallow bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery
162	Shallow bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery
177	Shallow bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, lab, and field meaurements	Plume leading edge
GM01A	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume, confirmation sampling
MW03	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, lab, and field	Plume
MW04	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
MW05	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
PZ06	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery
PZ07	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery

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Table 6-5. (cont.)

Well ID	Monitoring Depth Zone	Proposed or Existing	On-site/ Off-site	Analyses[a]	Rationale
PZ11	Shallow bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume
136	Intermediate bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery
181	Intermediate bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery
185	Intermediate bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery
201	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, density, conventionals, and field meaurements	Background
202	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, PCBs, pest, and field meaurements	Background
203	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Plant area
205	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, lab, and field meaurements	Plume
210	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Downstrike of plant area
215	Intermediate bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, lab, and field meaurements	Plume
216	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, lab, and field meaurements	Plume
232	Intermediate bedrock	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, and field meaurements	Viscose basins 1–8
GM02A	Intermediate bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume
GM02B	Intermediate bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume
GM04	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10

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Table 6-5. (cont.)

Well ID	Monitoring Depth Zone	Proposed or Existing	On-site/ Off-site	Analyses[a]	Rationale
GM05	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Confirmation sampling, OU-10
GM07	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery
GM08	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Viscose basins
GM09	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume
PW0	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume
PW02	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume, confirmation sampling
PW03	Intermediate bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, and field meaurements	Plume periphery
301	Deep bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, density, conventionals, and field meaurements	Background
302	Deep bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, PCBs, pest, and field meaurements	Background
303	Deep bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, PCBs, pest, and field meaurements	Plant area
305	Deep bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, lab, and field	Plume
315	Deep bedrock	Existing	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, and field meaurements	Plume leading edge
316	Deep bedrock	Existing	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, and field	Plume
343	Deep bedrock	Proposed	Off-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, and field	Plume leading edge
WP01	Viscose basin	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, COD, lab, and field	Viscose basin pore water
WP02	Viscose basin	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, COD, and field meaurements	Viscose basin pore water

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Table 6-5. (cont.)

Well ID	Monitoring Depth Zone	Proposed or Existing	On-site/ Off-site	Analyses[a]	Rationale
WP03	Viscose basin	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, COD, and field meaurements	Viscose basin pore water
WP04	Viscose basin	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, COD, lab, and field	Viscose basin pore water
WP05	Viscose basin	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, COD, and field meaurements	Viscose basin pore water
WP06	Viscose basin	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, COD, and field meaurements	Viscose basin pore water
WP07	Viscose basin	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, As speciation, ammonia nitrogen, density, conventionals, COD, lab, and field meaurements	Viscose basin pore water
WP08	Viscose basin	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, COD, and field meaurements	Viscose basin pore water
WP09	Viscose basin	Proposed	On-site	TCL VOCs, TCL SVOCs, TAL inorganics, ammonia nitrogen, density, conventionals, COD, and field meaurements	Viscose basin pore water

Note: Bolded well IDs indicate that the well is part of the OU-10 workplan.

[a] Parameter groups are as follows:

As speciation	arsenic speciation [As(III) / As (v)]
COD	chemical oxygen demand
Conventionals	alkalinity, chloride, sulfate, silica, total dissolved solids
Field measurements	pH, temperature, specific conductance, dissolved oxygen, Eh, turbidity, iron speciation
Lab	samples collected for lab testing of carbon disulfide hydrolysis
PCBs	polychlorinated biphenyls
Pest	organochlorinated pesticides
TAL inorganics	target analyte list inorganics (EPA 1996), includes chromium speciation [Cr(VIII)/Cr(VI)]
TCL SVOCs	target compound list SVOCs (EPA 1994)
TCL VOCs	target compound list VOCs (EPA 1994)

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Table 6-6. Summary of screening preliminary evaluation of potential in-situ remediation technologies for viscose basins 9–11

In-Situ Technology	Probable Effectiveness	Implementability	Cost	Comments
Biological				
Vermiculture	Moderate to high; Fate of CS_2 is unknown	Operationally intensive. Significant excavation required.	Unknown	New technology—has not been demonstrated at full scale. Cost, implementability, and market factors are uncertain. Bench and field testing required. Potential for some cost to be offset by sale of castings.
Bioremediation	Low to moderate	Operationally intensive. In-situ application may not be feasible due to the low load-bearing capacity of the sludge.	High	May be technically infeasible to achieve sufficient aeration to support aerobic biodegradation.
Physical				
Electrical Resistance Heating	Moderate	Placement of electrodes may be complicated by low load-bearing capacity of the viscose. Control of off gases required.	Potentially high	Relatively new technology. Would require bench testing to evaluate feasibility. Effect on bound fraction of CS_2 uncertain.
In-Situ Pyrolysis	Moderate	Difficult to develop and control proper conditions. Control of off gases required.	High	New technology for remediation. Would be difficult to secure regulatory approval.
Containment	Low to moderate	Placement of the cap complicated by the low load-bearing capacity of the sludge.	Moderate	Would not eliminate CS_2 loading from the basins. Long-term integrity of the cap may be compromised by the inherent instability of the sludge.
Chemical				
Chemical oxidation	Moderate	High probability of off gassing. In-situ application may not be feasible.	High	Feasibility limited by the inability to achieve adequate chemical mixing. Substantial mass of chemicals required.
Solidification/ Stabilization	Low	In-situ application may not be feasible.	High	Unfavorable results during bench-scale testing. Feasibility limited by the inability to achieve adequate chemical mixing. Substantial mass of chemicals required. Problems with volume expansion.
Chemical grouting	Moderate	Complicated by scale of the viscose basins. Low load-bearing capacity of the sludge would complicate well installation.	High	Would require that additional containment measures (i.e., barrier walls and cap) be emplaced to eliminate all pathways to groundwater.

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Appendix A

Chemistry of Cellulose Xanthate—The Viscose Process

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Chemistry of Cellulose Xanthate---The Viscose Process

Cellulose is the principal fiber cell-wall material in green terrestrial and marine plants, and is the most abundant material in nature. Cellulose is a long, linear polymer of anhydroglucose units (Figure B1a), which is reflected in the thread-like structures of cellulose found in plant cell walls (Kirk and Othmer 1985).

The viscose process is responsible for the production of rayon, cellophane, and Hawaiian shirts. Rayon is a regenerated cellulose product prepared from cellulose that is chemically altered to form a xanthate (or thioester), which is subsequently decomposed to cellulose in the form known as rayon. As such, the formation of the cellulose xanthate (or viscose) is an intermediate step in the process.

Cellulose is first treated with sodium hydroxide (NaOH, 18–20 percent) to yield alkali cellulose (Figure B1b; R_{cell} indicates the anhydroglucose chain of cellulose). The alkali cellulose is then reacted with carbon disulfide (CS_2, 30–40 percent based on weight of dry cellulose) to generate sodium cellulose xanthate (Figure B1c). At this point, the average degree of xanthate substitution is approximately one xanthate group per two glucose units (a degree of substitution of 0.5; Kirk and Othmer 1949). The xanthation reaction (Figure B1c) should be regarded as an equilibrium reaction (e.g., reversible), with products heavily favored over reactants. The sodium cellulose xanthate is then allowed to age, or ripen, for several days, during which time, the degree of xanthate substitution is reduced, and the cellulose chains assume the desired orientation with respect to each other. Ripened viscose has a degree of substitution of 0.3 to 0.4, or approximately one xanthate group for every three glucose units (Hermens 1949). The sodium cellulose xanthate is then dissolved in dilute sodium hydroxide to yield viscose, a golden-brown, thick solution that contains 6–8 percent sodium cellulose xanthate and 6–7 percent sodium hydroxide (Kirk and Othmer 1949).

Excess carbon disulfide (CS_2) that does not react with alkali cellulose (reaction in Figure B1c) is consumed in a secondary reaction with sodium hydroxide (Figure B2a) to produce sodium trithiocarbonate, sodium carbonate, and water. The trithiocarbonate is responsible for the orange color of the cellulose xanthate, and for the brown color of the viscose; cellulose xanthate is almost colorless or faintly yellow (Hermans 1949). Another secondary reaction occurring during xanthation is the reaction of sodium cellulose xanthate with sodium hydroxide to form sodium monothiocarbonate, sodium hydrosulfide, and cellulose (Figure B2b). These secondary reactions are essentially irreversible under basic conditions.

The regeneration step is performed in a sulfuric acid bath (10 percent by volume was used at the Avtex facility). During the regeneration reaction, the sodium cellulose xanthate reacts with acid to form cellulose xanthogenic acid, from which the carbon disulfide spontaneously dissociates (Figure B2c). The byproducts of the xanthation

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process (see Figures A2a and b) are also decomposed in the acid bath (Figure B2d), producing sodium sulfate, hydrogen sulfide, carbon disulfide, carbon dioxide, and water.

The viscose present in the viscose basins represents material in which the aging (or ripening) reactions have been carried to their environmental endpoints. Because the formation of sodium cellulose xanthate is a reversible reaction (Figure B1c), carbon disulfide will be liberated slowly during environmental aging. This reaction, which liberates carbon disulfide, proceeds rapidly under acidic conditions but will proceed slowly under the basic conditions present in the viscose basins. In the presence of sodium hydroxide, this liberated carbon disulfide will react to form sodium trithiocarbonate and sodium carbonate (Figure B2a). This reaction will likely continue until all of the sodium cellulose xanthate has decomposed, or until the viscosity of the material increases to the point where the reaction can only occur very slowly (i.e., it becomes diffusion limited).

The implications of this chemistry are that only a fraction of the original carbon disulfide remains bound to the aged material in the viscose basins. The carbon disulfide liberated during this aging process either remains entrained in the solidified viscose, reacts to form decomposition byproducts (Figure B2c), or has percolated to groundwater. The slow release of carbon disulfide from the aging viscose suggests that carbon disulfide has been released to groundwater as an aqueous phase, rather than as free product or as a dense non-aqueous phase liquid (DNAPL).

References

Hermans, P.H. 1949. Physics and chemistry of cellulose fibers with particular reference to rayon. Elsevier Publishing Company, Inc., New York.

Kirk, R.E., and D.F. Othmer. 1949. Encyclopedia of chemical technology. John Wiley & Sons, Inc., New York.

Kirk, R.E., and D.F. Othmer. 1985. Concise encyclopedia of chemical technology. John Wiley & Sons, Inc., New York.

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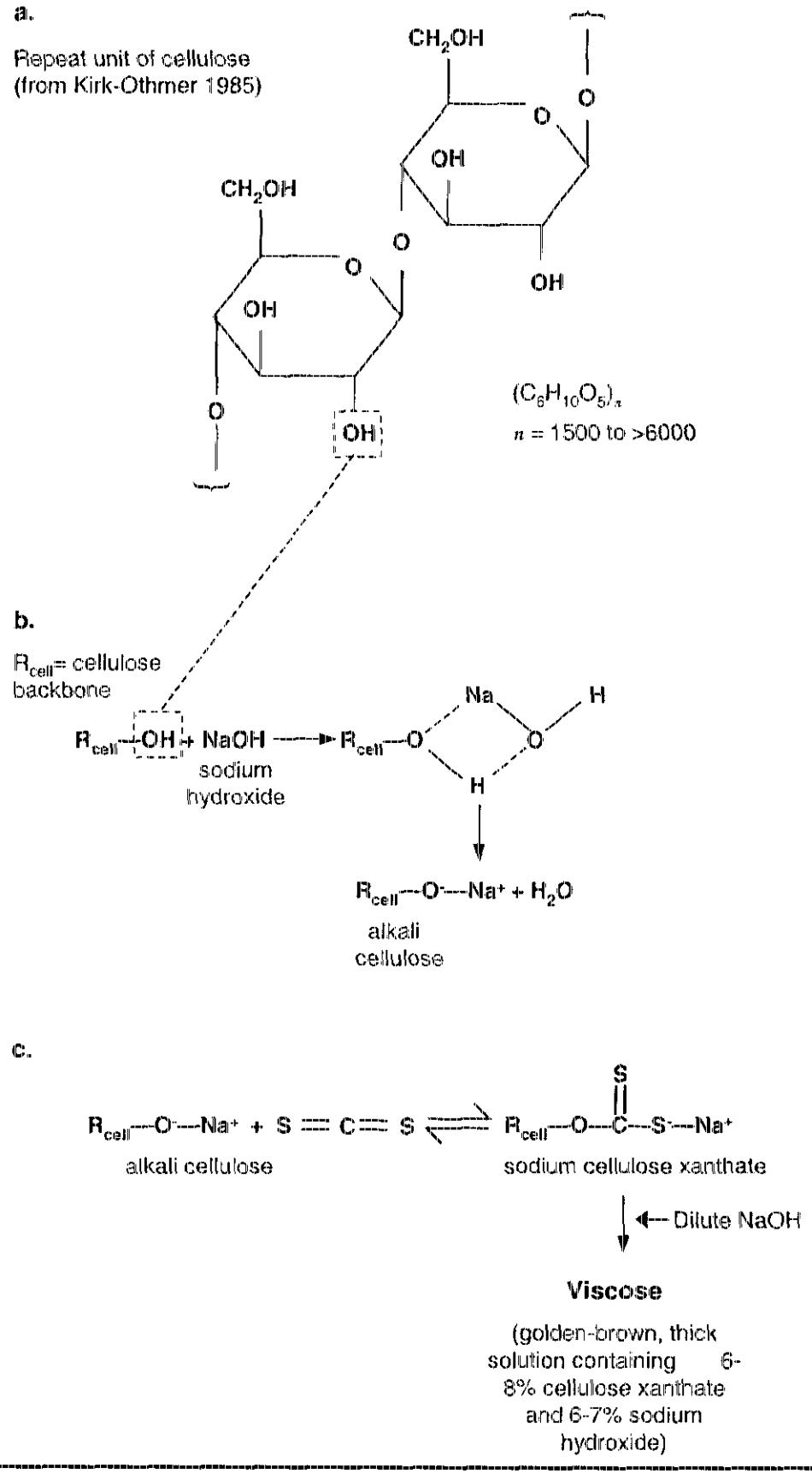

Figure A1. Chemical structure of cellulose (a), and chemical reactions in formation of viscose (b,c).

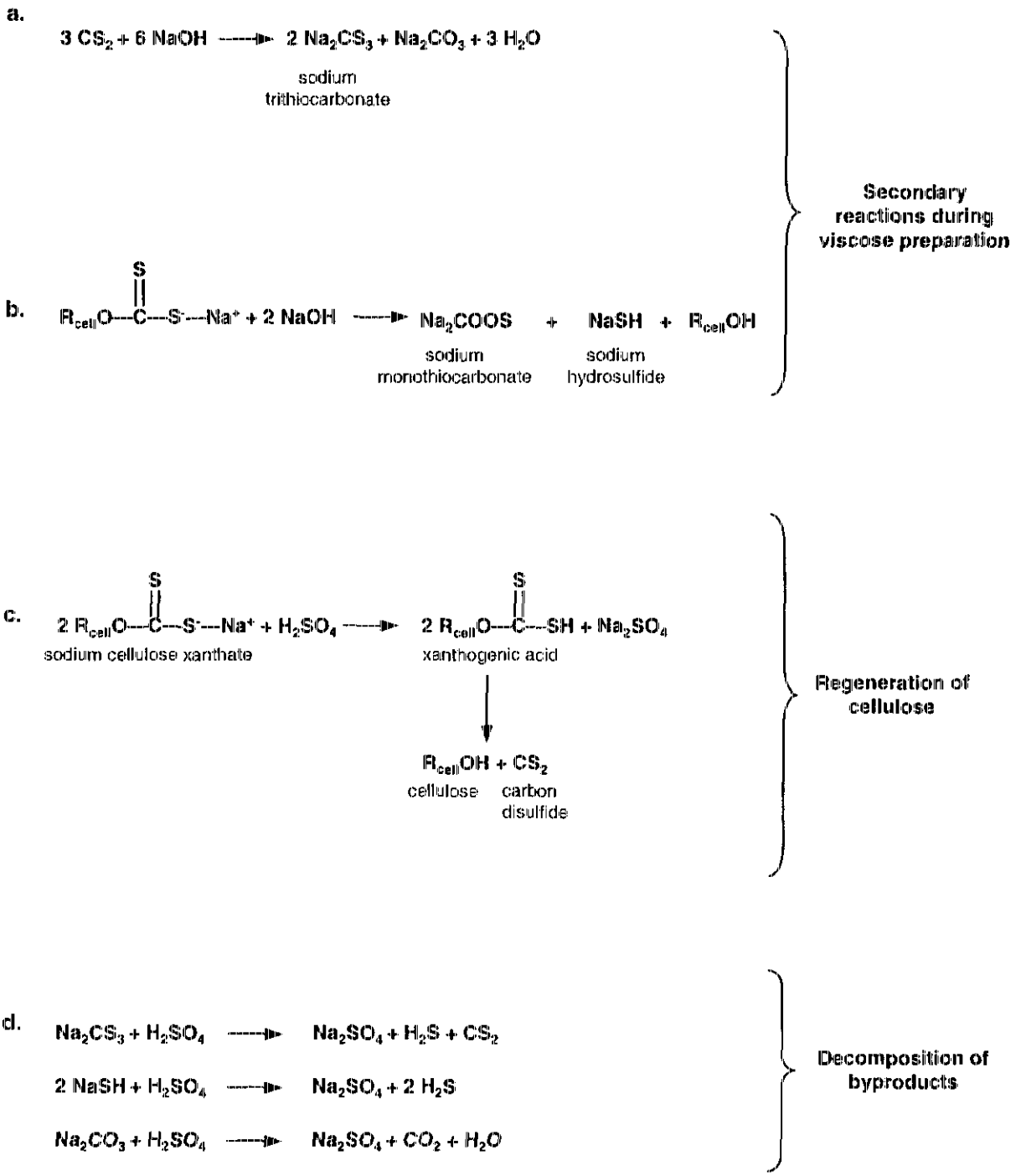

Figure A2. Secondary reactions during viscose preparation (a,b), regeneration of cellulose (c), and decomposition of byproducts during regeneration reaction (d).

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Appendix B

Single-Well Hydraulic Conductivities

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Table B-1. Single-well hydraulic conductivity measurements, Avtex site

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-004	004	OMW	11562899.77	7021555.189	WW	Treatment Plant	6.90E-05	-9.58E+00	27	37	Pressure	--	ERM 1993
GW-ON-005	005	OMW	11563843.45	7018960.846	SB	SB-02	7.80E-05	-9.46E+00	27	37	Pressure	--	ERM 1993
GW-ON-008	008	OMW	11565809.12	7018410.492	FA	FA-06	5.20E-05	-9.86E+00	27	37	Pressure	--	ERM 1993
GW-ON-009	009	OMW	11565226.54	7016769.055	SB	SB-05	4.80E-05	-9.94E+00	37	47	Pressure	--	ERM 1993
GW-ON-010	010	OMW	11564697.47	7017467.856	SB	SB-06	3.80E-05	-1.02E+01	37	47	Pressure	--	ERM 1993
GW-ON-011	011	OMW	11564568.86	7017838.342	SB	SB-05	2.40E-05	-1.06E+01	37	47	Pressure	--	ERM 1993
GW-ON-012	012	OMW	11564742.54	7018658.256	FA	FA-01	2.60E-05	-1.05E+01	47	57	Pressure	--	ERM 1993
GW-ON-013	013	OMW	11564560.67	7019150.1	FA	FA-02	2.90E-05	-1.04E+01	47	57	Pressure	--	ERM 1993
GW-ON-014	014	OMW	11564492.35	7019529.82	FA	FA-03	3.50E-05	-1.03E+01	47	57	Pressure	--	ERM 1993
GW-ON-017	017	OMW	11562879.19	7021204.718	WW	Emergency Basin	1.10E-04	-9.12E+00	57	67	Pressure	--	ERM 1993
GW-ON-021	021	OMW	11564255.25	7018149.907	SB	SB-04	1.00E-04	-9.21E+00	57	67	Pressure	--	ERM 1993
GW-ON-022	022	OMW	11563936.85	7018677.577	SB	SB-04	9.60E-05	-9.25E+00	57	67	Pressure	--	ERM 1993
GW-ON-023	023	OMW	11563495.88	7019272.002	SB	SB-02	2.30E-03	-6.07E+00	67	77	Pressure	--	ERM 1993
GW-ON-024	024	OMW	11563157.01	7019843.287	SB	SB-01	2.00E-03	-6.21E+00	67	77	Pressure	--	ERM 1993
GW-ON-025	025	OMW	11562944.32	7020322.95	SB	SB-01	2.20E-03	-6.12E+00	67	77	Pressure	--	ERM 1993
GW-ON-026	026	OMW	11562902.19	7020627.781	SB	SB-01	8.50E-05	-9.37E+00	77	87	Pressure	--	ERM 1993
GW-ON-101	101	S BMW	11566965.83	7022129.775	On-site	Background	5.70E-05	-9.77E+00	77	87	Pressure	--	ERM 1993
GW-ON-102	102	S BMW	11566828.18	7019323.745	On-site/Off-site Ground Water	Southeastern portion of site	6.30E-05	-9.67E+00	77	87	Pressure	--	ERM 1993
GW-ON-106	106	S BMW	11566694.58	7021906.145	On-site	POLY PCB	1.90E-04	-8.57E+00	97	107	Pressure	--	ERM 1993
GW-ON-107	107	S BMW	11565526.51	7020612.586	On-site/Off-site Ground Water	ZN RECOV	1.30E-04	-8.95E+00	97	107	Pressure	--	ERM 1993
GW-ON-108	108	S BMW	11565796.32	7018412.52	FA	FA-06	1.60E-04	-8.74E+00	97	107	Pressure	--	ERM 1993
GW-ON-109	109	S BMW	11565236.11	7016755.115	SB	SB-05	3.60E-05	-1.02E+01	107	117	Pressure	--	ERM 1993
GW-ON-110	110	S BMW	11564676.07	7017469.494	SB	SB-05	2.00E-05	-1.08E+01	107	117	Pressure	--	ERM 1993
GW-ON-111	111	S BMW	11564556.66	7017860.808	SB	SB-05	2.40E-05	-1.06E+01	107	117	Pressure	--	ERM 1993
GW-ON-112	112	S BMW	11564742.5	7018671.406	FA	FA-01	2.40E-05	-1.06E+01	117	127	Pressure	--	ERM 1993
GW-ON-113	113	S BMW	11564562.97	7019142.749	FA	FA-02	1.30E-05	-1.13E+01	117	127	Pressure	--	ERM 1993
GW-ON-114	114	S BMW	11564471.88	7019521.626	FA	FA-03	1.60E-05	-1.09E+01	117	127	Pressure	--	ERM 1993
GW-ON-115	115	S BMW	11563306.57	7018223.853	On-site/Off-site Ground Water	Rivermont Acres; north of stream	3.60E-05	-1.02E+01	127	137	Pressure	--	ERM 1993
GW-ON-116	116	S BMW	11564266.25	7020146.983	SB	VB-10	1.30E-05	-1.13E+01	127	137	Pressure	--	ERM 1993
GW-ON-117	117	S BMW	11562876.36	7021214.757	WW	Emergency Basin	6.00E-06	-1.20E+01	127	137	Pressure	--	ERM 1993
GW-ON-118	118	S BMW	11564897.52	7022154.409	VB	VB-05	6.00E-06	-1.20E+01	137	147	Pressure	--	ERM 1993
GW-ON-119	119	S BMW	11564345.22	7022305.402	VB	VB-05	6.70E-06	-1.19E+01	137	147	Pressure	--	ERM 1993
GW-ON-120	120	S BMW	11564039.34	7022311.436	VB	VB-04	6.00E-06	-1.20E+01	137	147	Pressure	--	ERM 1993
GW-ON-201	201	I BMW	11566971.24	7022136.589	On-site	Background	0.00012	-9.03E+00	147	157	Pressure	--	ERM 1993
GW-ON-202	202	I BMW	11566812.84	7019325.826	On-site/Off-site Ground Water	Southeastern portion of site	0.00009	-9.32E+00	147	157	Pressure	--	ERM 1993
GW-ON-203	203	I BMW	11565235.36	7020210.268	FA	Fly Ash Pile	0.0001	-9.21E+00	147	157	Pressure	--	ERM 1993
GW-ON-204	204	I BMW	11562893.84	7021592.037	WW	Treatment Plant	0.000061	-9.70E+00	157	167	Pressure	--	ERM 1993
GW-ON-205	205	I BMW	11563887.69	7018994.959	SB	SB-02	0.000041	-1.01E+01	157	167	Pressure	--	ERM 1993
GW-ON-207	207	I BMW	11565478.93	7020579.895	On-site/Off-site Ground Water	ZN RECOV	0.000043	-1.01E+01	157	167	Pressure	--	ERM 1993
GW-ON-210	210	I BMW	11564691.74	7017477.817	SB	SB-05	0.001	-6.91E+00	167	177	Pressure	--	ERM 1993
GW-ON-215	215	I BMW	11563297.87	7018223	On-site/Off-site Ground Water	Rivermont Acres; north of stream	0.00077	-7.17E+00	167	177	Pressure	--	ERM 1993
GW-ON-216	216	I BMW	11564259.16	7020143.011	SB	VB-10	0.00089	-7.02E+00	167	177	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	3.2E-06	-12.6523597	96	109	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	3.8E-06	-12.4805095	109	121	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	4.7E-06	-12.267948	227	237	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	5.2E-06	-12.1668519	96	109	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	6.3E-06	-11.9749609	96	109	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	6.6E-06	-11.9284409	84	96	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	9.4E-06	-11.5748009	237	247	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	9.9E-06	-11.5229758	84	96	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000011	-11.4176153	84	96	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000018	-10.9251388	207	217	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00002	-10.8197783	207	217	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000022	-10.7244681	158	170	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000023	-10.6800163	170	182	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000027	-10.5196737	217	227	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000029	-10.4482147	170	182	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00003	-10.4143132	207	217	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00003	-10.4143132	217	227	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000035	-10.2601625	197	207	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000035	-10.2601625	133	145	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000035	-10.2601625	133	145	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000036	-10.2319916	170	182	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000037	-10.2045926	197	207	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000039	-10.1519489	133	145	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000042	-10.0778409	217	227	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.000065	-9.64112329	197	207	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00032	-8.04718956	177	187	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00032	-8.04718956	177	187	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00043	-7.75172535	177	187	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00051	-7.58109983	158	170	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00069	-7.27881896	158	170	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00099	-6.92795799	72	84	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.00099	-6.91780561	72	84	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0011	-6.8124451	72	84	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0014	-6.57126304	145	158	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0014	-6.57126304	145	158	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0015	-6.50229017	60	72	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0017	-6.37712703	60	72	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0017	-6.37712703	60	72	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0018	-6.31996861	145	158	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0021	-6.16581793	121	133	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0022	-6.11929792	121	133	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0023	-6.07484616	47	60	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0023	-6.07484616	121	133	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0025	-5.99146455	47	60	Pressure	--	ERM 1993
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	0.0027	-5.91450351	47	60	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	3.6E-06	-12.5345767	98	108	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	3.6E-06	-12.5345767	108	118	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	3.7E-06	-12.5071777	78	88	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	6.8E-06	-11.8985879	78	88	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	6.8E-06	-11.8985879	98	108	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	7.2E-06	-11.8414295	118	128	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	9.9E-06	-11.5229758	18	28	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000014	-11.1764532	78	88	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000019	-10.8710716	138	148	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000019	-10.8710716	139	148	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000019	-10.8710716	168	178	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000019	-10.8710716	168	178	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000022	-10.7244681	138	148	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000031	-10.3815234	158	168	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000032	-10.3497747	158	168	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000052	-9.86426684	148	158	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.000052	-9.86426684	158	168	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.00012	-9.02801882	128	138	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.00012	-9.02801882	128	138	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.00013	-8.94797611	88	98	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.00014	-8.87386814	128	138	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.00015	-8.80487526	88	98	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.00019	-8.56848549	88	98	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.00071	-7.25024559	38	48	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.00091	-7.00206596	38	48	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.00096	-6.94857727	38	48	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0024	-6.03228654	28	38	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0025	-5.99146455	28	38	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0025	-5.99146455	68	78	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0026	-5.95224383	58	68	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0026	-5.87813586	68	78	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0029	-5.84304454	28	38	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0029	-5.84304454	48	58	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0029	-5.84304454	48	58	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0029	-5.84304454	58	68	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0029	-5.84304454	58	68	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0029	-5.84304454	68	78	Pressure	--	ERM 1993
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	0.0032	-5.74460447	48	58	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	3.4E-06	-12.5917351	70	80	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000006	-12.0237511	268	278	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	6.2E-06	-11.9909613	60	70	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	6.2E-06	-11.9909613	90	100	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	6.2E-06	-11.9909613	90	100	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	6.4E-06	-11.9592126	188	198	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	6.4E-06	-11.9592126	288	298	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	6.8E-06	-11.8985879	90	100	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	8.6E-06	-11.6637484	50	60	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000011	-11.4176153	288	298	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000013	-11.2505612	168	178	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000014	-11.1764532	100	110	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000019	-10.8710716	100	110	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000024	-10.6374567	228	238	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000024	-10.6374567	268	278	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000024	-10.6374567	150	160	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000025	-10.5966347	100	110	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000026	-10.557414	218	228	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000026	-10.557414	228	238	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000027	-10.5196737	140	150	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000028	-10.483306	218	228	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000031	-10.3815234	120	130	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000031	-10.3815234	140	150	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000031	-10.3815234	150	160	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000032	-10.3497747	218	228	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000034	-10.28915	150	160	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000037	-10.2045926	120	130	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000037	-10.2045926	160	170	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000037	-10.2045926	160	170	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000038	-10.1779244	198	208	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000038	-10.1779244	278	288	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000042	-10.0778409	228	238	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000044	-10.0313209	110	120	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000045	-10.0088461	198	208	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000049	-9.92369026	120	130	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000052	-9.86426684	208	218	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000055	-9.80817737	130	140	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000056	-9.79015887	268	278	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000058	-9.75506755	208	218	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000061	-9.70463669	238	248	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00007	-9.56701532	208	218	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00007	-9.56701532	248	258	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00007	-9.56701532	278	288	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000075	-9.49802244	248	258	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00008	-9.43348392	278	288	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00008	-9.43348392	160	170	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000083	-9.39666995	258	268	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.000096	-9.25116237	248	258	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.0001	-9.21034037	258	268	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.0001	-9.21034037	130	140	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00012	-9.02801882	238	248	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00012	-9.02801882	258	268	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00012	-9.02801882	130	140	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00012	-9.02801882	170	180	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00014	-8.87386814	80	90	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00014	-8.87386814	110	120	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00014	-8.87386814	110	120	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00015	-8.80487526	80	90	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00015	-8.80487526	170	180	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00018	-8.62255371	40	50	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00018	-8.62255371	40	50	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00018	-8.62255371	40	50	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00018	-8.62255371	80	90	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00035	-7.9575774	20	30	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00038	-7.87533931	20	30	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00041	-7.7993534	20	30	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00046	-7.68428407	178	188	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00051	-7.58109983	198	208	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00052	-7.56168175	178	188	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00065	-7.3385382	238	248	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00091	-7.00206596	30	40	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.00092	-6.99113689	178	188	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.0011	-6.8124451	30	40	Pressure	--	ERM 1993
GW-ON-303	303	D BMW	11565234.96	7020200.549	FA	Fly Ash Pile	0.0012	-6.72543372	30	40	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	3.1E-06	-12.6841084	138	148	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	3.1E-06	-12.6841084	168	178	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	3.7E-06	-12.5071777	58	68	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	5.2E-06	-12.1668519	88	98	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	5.2E-06	-12.1668519	88	98	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	5.3E-06	-12.1478037	98	108	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	5.3E-06	-12.1478037	138	148	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	5.3E-06	-12.1478037	178	188	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	5.3E-06	-12.1478037	178	188	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	5.3E-06	-12.1478037	188	198	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	5.3E-06	-12.1478037	188	198	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	6.1E-06	-12.0072218	210	220	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	6.2E-06	-11.9909613	128	138	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	6.3E-06	-11.9749609	148	158	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	6.3E-06	-11.9749609	178	188	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	6.3E-06	-11.9749609	188	198	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00001	-11.5129255	210	220	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000011	-11.4176153	58	68	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000011	-11.4176153	128	138	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000011	-11.4176153	138	148	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000011	-11.4176153	148	158	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000011	-11.4176153	168	178	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000012	-11.3306039	230	240	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000012	-11.3306039	240	250	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000012	-11.3306039	260	270	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000014	-11.1764532	250	260	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000015	-11.1074604	108	118	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000017	-10.9822972	260	270	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000017	-10.9822972	48	58	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000018	-10.9251388	230	240	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000018	-10.9251388	250	260	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000018	-10.9251388	250	260	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000019	-10.8710716	290	300	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000019	-10.8710716	108	118	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00002	-10.8197783	230	240	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000021	-10.7709881	290	300	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000021	-10.7709881	128	138	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000024	-10.6374567	210	220	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000024	-10.6374567	220	230	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000024	-10.6374567	240	250	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000024	-10.6374567	260	270	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000024	-10.6374567	280	290	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000025	-10.5966347	280	290	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000031	-10.3815234	280	290	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000031	-10.3815234	118	128	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000032	-10.3497747	108	118	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000032	-10.3497747	118	128	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000037	-10.2045926	118	128	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000039	-10.1519489	290	300	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000061	-9.70463669	220	230	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000065	-9.64112329	78	88	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000068	-9.59600285	78	88	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000068	-9.59600285	78	88	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	7.90E-05	-9.44606271	220	230	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00009	-9.31570089	158	168	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	9.10E-05	-9.30465105	240	250	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000091	-9.30465105	158	168	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000092	-9.29372198	190	200	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.000098	-9.23054308	190	200	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00011	-9.11503019	180	190	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00011	-9.11503019	180	190	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00011	-9.11503019	200	210	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00011	-9.11503019	38	48	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00011	-9.11503019	158	168	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00012	-9.02801882	170	180	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00012	-9.02801882	190	200	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00012	-9.02801882	200	210	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00014	-8.87386814	180	190	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00015	-8.80487526	38	48	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00016	-8.74033674	200	210	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00019	-8.56848649	38	48	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00033	-8.0164179	270	280	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00037	-7.90200755	270	280	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00047	-7.66277786	270	280	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00086	-7.05857817	68	78	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00093	-6.98032597	48	58	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00095	-6.95904857	68	78	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.00097	-6.93821449	68	78	Pressure	--	ERM 1993
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	0.001	-6.90775526	48	58	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	4.3E-07	-14.6594806	75	85	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	4.3E-07	-14.6594806	95	105	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	7.3E-07	-14.1302213	95	105	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	5.4E-06	-12.1291116	228	238	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	6.4E-06	-11.9592126	208	218	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000011	-11.4176153	228	238	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000013	-11.2505612	228	238	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000021	-10.7709881	198	208	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000021	-10.7709881	198	208	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000023	-10.6800163	218	228	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000023	-10.6800163	218	228	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000025	-10.5965347	198	208	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000027	-10.5196737	278	288	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000028	-10.483306	278	288	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000033	-10.319003	288	298	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000037	-10.2045926	258	268	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000038	-10.1779244	208	218	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000043	-10.0543104	248	258	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000044	-10.0313209	208	218	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000047	-9.96536296	248	258	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000047	-9.96536296	258	268	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000048	-9.94430955	248	258	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000048	-9.94430955	258	268	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000051	-9.88368493	218	228	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.000068	-9.59600285	288	298	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00008	-9.43348392	288	298	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00011	-9.11503019	238	248	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00011	-9.11503019	238	248	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00016	-8.74033674	238	248	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer Bouwer and Rice Case Number	Source
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00016	-8.74033674	85	95	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00017	-8.67971212	85	95	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00022	-8.42188301	115	125	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00025	-8.29404964	38	48	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00026	-8.25482893	38	48	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00027	-8.2170686	115	125	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00027	-8.2170886	38	48	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00028	-8.18072095	105	115	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00028	-8.18072095	115	125	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.0003	-8.11172808	105	115	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00031	-8.07893826	105	115	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00036	-7.92940653	48	58	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00054	-7.52394142	135	145	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00055	-7.50559228	125	135	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00067	-7.30823285	125	135	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00068	-7.29341776	135	145	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00068	-7.29341776	77	87	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00069	-7.27881896	125	135	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.0007	-7.26443022	135	145	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00085	-7.07027421	77	87	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00086	-7.05857817	77	87	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.0009	-7.01311579	47	57	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00098	-6.92795799	47	57	Pressure	--	ERM 1993
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	0.00098	-6.92795799	47	57	Pressure	--	ERM 1993
GW-ON-316	316	D BMW	11564254.59	7020140.66	SB	VB-10	0.00029	-8.14562963	48	58	Pressure	--	ERM 1993
GW-ON-GM1A	GM-1A	S BMW	11563430.21	7019555.024	On-Site	GW	0.00039	-7.84936382	48	58	Pressure	--	ERM 1993
GW-ON-GM1A	GM-1A	S BMW	11563430.21	7019555.024	On-Site	GW	0.00031	-8.07893826	78	88	Pressure	--	ERM 1993
GW-ON-GM1A	GM-1A	S BMW	11563430.21	7019555.024	On-Site	GW	0.00025	-8.29404964	78	88	Pressure	--	ERM 1993
GW-ON-GM1A	GM-1A	S BMW	11563430.21	7019555.024	On-Site	GW	0.0003	-8.11172808	78	88	Pressure	--	ERM 1993
GW-ON-GM1A	GM-1A	S BMW	11563430.21	7019555.024	On-Site	GW	0.00028	-8.18072095	88	98	Pressure	--	ERM 1993
GW-ON-GM1A	GM-1A	S BMW	11563430.21	7019555.024	On-Site	GW	0.00024	-8.33487163	88	98	Pressure	--	ERM 1993
GW-ON-GM1A	GM-1A	S BMW	11563430.21	7019555.024	On-Site	GW	0.00028	-8.18072095	88	98	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	4.8E-07	-14.5494797	157	167	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	5.6E-07	-14.3602377	103	113	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	7.4E-07	-14.1166157	44	54	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	7.6E-07	-14.0899474	144	154	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	7.9E-07	-14.0512329	97	107	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	8E-07	-14.0386541	84	94	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	8.2E-07	-14.0139615	53	63	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	9.7E-07	-13.8459698	85	95	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	1.1E-06	-13.7202004	115	125	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	1.1E-06	-13.7202004	85	95	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	1.1E-06	-13.7202004	93	93	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	1.2E-06	-13.633189	91	101	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	1.2E-06	-13.633189	91	101	Pressure	--	ERM 1993
GW-ON-GM2B	GM-2B	I BMW	11563435.04	7018523.049	On-Site	GW	1.5E-06	-13.4100454	136	146	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	1.6E-06	-13.3455069	117	127	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	2.2E-06	-13.0270532	104	114	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	2.7E-06	-12.8222588	84	94	Pressure	--	ERM 1993
GW-ON-GM1B	GM-1B	I BMW	11563423.79	7019552.018	On-Site	GW	2.9E-06	-12.7507996	77	87	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	3.3E-06	-12.6215881	71	81	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	3.3E-06	-12.6215881	71	81	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	4.4E-06	-12.333906	63	73	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	8.6E-06	-11.6637484	71	81	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	8.7E-06	-11.6521875	81	91	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	8.8E-06	-11.6407588	63	73	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	9.2E-06	-11.5963071	107	117	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	0.000011	-11.4176153	107	117	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	0.000013	-11.2505612	97	107	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.000014	-11.1764532	93	103	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	0.000016	-11.0429218	117	127	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.000016	-11.0429218	94	104	Pressure	--	ERM 1993
GW-ON-GM1B	GM-1B	I BMW	11563423.79	7019552.018	On-Site	GW	0.000018	-10.9251388	77	87	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.000019	-10.8710716	135	145	Pressure	--	ERM 1993
GW-ON-GM1B	GM-1B	I BMW	11563423.79	7019552.018	On-Site	GW	0.000022	-10.7244681	87	97	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	0.000028	-10.483306	117	127	Pressure	--	ERM 1993
GW-ON-GM1B	GM-1B	I BMW	11563423.79	7019552.018	On-Site	GW	0.000034	-10.28915	87	97	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	0.000042	-10.0778409	87	97	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	0.000042	-10.0778409	97	107	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	0.000048	-9.94430955	63	73	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	0.000069	-9.58140405	45	55	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	0.00007	-9.56701532	45	55	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	0.000076	-9.48477722	45	55	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	0.0001	-9.21034037	41	51	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	0.00011	-9.11503019	41	51	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	0.00012	-9.02801882	137	147	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	0.00012	-9.02801882	41	51	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	0.00013	-8.94797611	114	124	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00014	-8.87386814	114	124	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00015	-8.80487526	115	125	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	0.00016	-8.74033674	137	147	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00017	-8.67971212	114	124	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00017	-8.67971212	115	125	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00017	-8.67971212	115	125	Pressure	--	ERM 1993
GW-ON-GM2A	GM-2A	I BMW	11563466.93	7018542.341	On-Site	GW	0.00019	-8.56848649	137	147	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00021	-8.46840303	125	135	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00024	-8.33487163	125	135	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00027	-8.2170886	125	135	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00029	-8.14562963	54	64	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00029	-8.14562963	54	64	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00031	-8.07893826	54	64	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00031	-8.07893826	73	83	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00033	-8.0164179	73	83	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00036	-7.92940653	123	133	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00037	-7.90200755	73	83	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00038	-7.87533931	145	155	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.0004	-7.82404601	145	155	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00042	-7.77525585	123	133	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	0.00043	-7.75172535	61	71	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00043	-7.75172535	53	63	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00043	-7.75172535	53	63	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00043	-7.75172535	123	133	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00046	-7.68428407	145	155	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00046	-7.68428407	75	85	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	0.00046	-7.68428407	61	71	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00046	-7.68428407	53	63	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	0.0005	-7.60090246	65	75	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	0.00052	-7.56168175	61	71	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	0.00053	-7.54263355	35	45	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	0.00054	-7.52394142	35	45	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00054	-7.52394142	65	75	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	0.00057	-7.4698742	73	83	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00057	-7.4698742	111	121	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00058	-7.45248245	63	73	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	0.00059	-7.43538802	65	75	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	0.0006	-7.4165609	41	51	Pressure	--	ERM 1993
GW-ON-GM4	GM-4	I BMW	11563542.96	7022138.781	On-Site	GW	0.00061	-7.4020516	35	45	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	0.00061	-7.4020516	41	51	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00062	-7.38579108	74	84	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	0.00062	-7.38579108	93	103	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00062	-7.38579108	63	73	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00062	-7.38579108	113	123	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00063	-7.36979074	64	74	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00063	-7.36979074	103	113	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00065	-7.3385382	63	73	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	0.00066	-7.32327072	73	83	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00066	-7.32327072	71	81	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00066	-7.32327072	81	91	Pressure	--	ERM 1993
GW-ON-GM9	GM-9	I BMW	11563993.34	7018729.734	On-Site	GW	0.00067	-7.30823285	41	51	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00067	-7.30823285	111	121	Pressure	--	ERM 1993
GW-ON-GM2B	GM-2B	I BMW	11563435.04	7018523.049	On-Site	GW	0.0007	-7.26443022	106	116	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.0007	-7.26443022	111	121	Pressure	--	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00072	-7.23625935	64	74	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00074	-7.20886037	113	123	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00075	-7.19543735	64	74	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00075	-7.19543735	113	123	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00076	-7.18219212	95	105	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	0.00076	-7.18219212	73	83	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00077	-7.16912004	74	84	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00078	-7.15621664	71	81	Pressure	--	ERM 1993
GW-ON-GM3	GM-3	I BMW	11562899.39	7021933.384	On-Site	GW	0.00079	-7.14347761	74	84	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00079	-7.14347761	81	91	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.00079	-7.14347761	81	91	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00079	-7.14347761	103	113	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	0.0008	-7.13089883	93	103	Pressure	--	ERM 1993
GW-ON-PW1	PW-1	I BMW	11563983.1	7018743.288	On-Site	GW	0.0008	-7.13089883	71	81	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.0008	-7.13089883	103	113	Pressure	--	ERM 1993
GW-ON-GM7	GM-7	I BMW	11564555.02	7018021.957	On-Site	GW	0.00084	-7.08210867	93	103	Pressure	--	ERM 1993
GW-ON-GM2B	GM-2B	I BMW	11563435.04	7018523.049	On-Site	GW	0.00086	-7.05857817	106	116	Pressure	--	ERM 1993
GW-ON-GM2B	GM-2B	I BMW	11563435.04	7018523.049	On-Site	GW	0.00086	-7.05857817	106	116	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.0009	-7.01311579	75	85	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00094	-6.96963068	95	105	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00095	-6.95904857	95	105	Pressure	--	ERM 1993
GW-ON-GM5	GM-5	I BMW	11563000.73	7020535.923	On-Site	GW	0.00097	-6.93821449	75	85	Pressure	--	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.000892	-7.02204443	8	13	Slug	3	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	9.12E-05	-9.30245566	21	31	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	1.49E-05	-11.1141493	9	14	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.000264	-8.23956145	40	45	Slug	3	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.000719	-7.2376492	6	11	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00015	-8.80487526	41	46	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	7.99E-05	-9.43473471	26	36	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	7.76E-05	-9.46394313	25	35	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.000126	-8.97922865	9	19	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00172	-6.36543099	9	14	Slug	3	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.000735	-7.21564006	4	9	Slug	3	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00499	-5.30031937	2	7	Slug	3	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.000486	-7.62930193	2	5	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.000202	-8.50724286	4	9	Slug	3	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00562	-5.18142362	3	5	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563792.74	7019007.7	On-Site	GW	0.00153	-6.48248754	3	5	Slug	1	ERM 1993
GW-ON-PW2	PW-2	I BMW	11563574.66	7019273.112	On-Site	GW	9.39E-05	-9.27328017	25	47	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.0191	-3.95806694	25	45	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00871	-4.74328349	25	41	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000968	-6.94027847	25	45	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00657	-5.02524145	41	52	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	5.34E-07	-14.44287	18	39	Slug	1	ERM 1993

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00197	-6.22972174	25	47	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000356	-7.94057983	22	43	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00044	-7.72873583	52	85	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000112	-9.09701169	18	39	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00263	-5.94077143	52	77	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00598	-5.11933471	43	63	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000317	-8.05660878	43	63	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000624	-7.37936019	35	55	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	1.52E-06	-13.3968002	17	43	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	2.68E-07	-15.1322789	55	75	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000192	-8.55801519	22	43	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00102	-6.88795265	27	48	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000019	-10.8710716	15	35	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000633	-7.36504014	19	38	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000429	-7.75405364	160	185	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.0117	-4.44816644	160	186	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000453	-7.69961843	160	188	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00117	-6.75075153	160	186	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000071	-9.55283068	160	187	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.000408	-7.80424338	80	100	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00453	-5.39703334	78	100	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	6.86E-07	-14.1923882	160	183	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	3.96E-06	-12.4392665	160	180	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	4.14E-06	-12.3948148	230	250	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	6.9E-08	-16.4891593	230	250	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	2.44E-06	-12.9235125	280	303	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	7.53E-06	-11.7966155	280	300	Slug	1	ERM 1993
GW-ON-PW3	PW-3	I BMW	11563574.66	7019273.112	On-Site	GW	0.00045	-7.70626298	230	250	Slug	1	ERM 1993
GW-ON-004	004	OMW	11562899.77	7021555.189	WW	Treatment Plant	8.92E-04	-7.02204443	27	37	Slug	3	Unpublished, ERM
GW-ON-005	005	OMW	11563843.45	7018960.846	SB	SB-02	9.12E-05	-9.30245566	27	37	Slug	1	Unpublished, ERM
GW-ON-008	008	OMW	11565809.12	7018410.492	FA	FA-06	1.49E-05	-11.1141493	27	37	Slug	1	Unpublished, ERM
GW-ON-009	009	OMW	11565226.54	7016769.055	SB	SB-05	2.64E-04	-8.23956145	37	47	Slug	3	Unpublished, ERM
GW-ON-010	010	OMW	11564697.47	7017467.656	SB	SB-05	7.19E-04	-7.2376492	37	47	Slug	1	Unpublished, ERM
GW-ON-011	011	OMW	11564568.86	7017838.342	SB	SB-05	1.50E-04	-8.80487526	37	47	Slug	1	Unpublished, ERM
GW-ON-012	012	OMW	11564742.54	7018658.256	FA	FA-01	7.99E-05	-9.43473471	47	57	Slug	1	Unpublished, ERM
GW-ON-013	013	OMW	11564560.67	7019150.1	FA	FA-02	7.76E-05	-9.46394313	47	57	Slug	1	Unpublished, ERM
GW-ON-014	014	OMW	11564492.35	7019529.82	FA	FA-03	1.26E-04	-8.97922865	47	57	Slug	1	Unpublished, ERM
GW-ON-017	017	OMW	11562879.19	7021204.718	WW	Emergency Basin	1.72E-03	-6.36543099	57	67	Slug	3	Unpublished, ERM
GW-ON-021	021	OMW	11564255.25	7018149.907	SB	SB-04	7.35E-04	-7.21564006	57	67	Slug	3	Unpublished, ERM
GW-ON-022	022	OMW	11563936.85	7018677.577	SB	SB-04	4.99E-03	-5.30031937	57	67	Slug	3	Unpublished, ERM
GW-ON-023	023	OMW	11563495.88	7019272.002	SB	SB-02	4.86E-04	-7.62930193	67	77	Slug	1	Unpublished, ERM
GW-ON-024	024	OMW	11563157.01	7019843.287	SB	SB-01	2.02E-04	-8.50724286	67	77	Slug	3	Unpublished, ERM
GW-ON-025	025	OMW	11562944.32	7020322.95	SB	SB-01	5.62E-03	-5.18142362	67	77	Slug	1	Unpublished, ERM
GW-ON-026	026	OMW	11562902.19	7020627.781	SB	SB-01	1.53E-03	-6.48248754	77	87	Slug	1	Unpublished, ERM

Table B-1. (cont.)

ID	Source ID	Well Type	Easting	Northing	Monitoring Unit	Location	Average K (cm/sec)	Ln K	Top Depth (ft)	Bottom Depth (ft)	Test Type	Bouwer and Rice Case Number	Source
GW-ON-101	101	S BMW	11566965.83	7022129.775	On-site	Background	9.39E-05	-9.27328017	77	87	Slug	1	Unpublished, ERM
GW-ON-102	102	S BMW	11566828.18	7019323.745	On-site/Off-site Ground Water	Southeastern portion of site	1.91E-02	-3.95806694	77	87	Slug	1	Unpublished, ERM
GW-ON-103	103	S BMW	11565232.33	7020219.504	--	--	8.71E-03	-4.74328349	25	41	Slug	1	Unpublished, ERM
GW-ON-104	104	S BMW	11562896.71	7021568.701	--	--	9.68E-04	-6.94027847	25	45	Slug	1	Unpublished, ERM
GW-ON-105	105	S BMW	11563901.45	7018997.469	--	--	6.57E-03	-5.02524145	41	52	Slug	1	Unpublished, ERM
GW-ON-106	106	S BMW	11566694.58	7021906.145	On-site	POLY PCB	5.34E-07	-14.44287	97	107	Slug	1	Unpublished, ERM
GW-ON-107	107	S BMW	11565526.51	7020612.586	On-site/Off-site Ground Water	ZN RECOV	1.97E-03	-6.22972174	97	107	Slug	1	Unpublished, ERM
GW-ON-108	108	S BMW	11565796.32	7018412.52	FA	FA-06	3.56E-04	-7.94057983	97	107	Slug	1	Unpublished, ERM
GW-ON-109	109	S BMW	11565236.11	7016755.115	SB	SB-05	4.40E-04	-7.72873583	107	117	Slug	1	Unpublished, ERM
GW-ON-110	110	S BMW	11564676.07	7017469.494	SB	SB-05	1.12E-04	-9.09701169	107	117	Slug	1	Unpublished, ERM
GW-ON-111	111	S BMW	11564556.66	7017860.808	SB	SB-05	2.63E-03	-5.94077143	107	117	Slug	1	Unpublished, ERM
GW-ON-112	112	S BMW	11564742.5	7018671.406	FA	FA-01	5.98E-03	-5.11933471	117	127	Slug	1	Unpublished, ERM
GW-ON-113	113	S BMW	11564562.97	7019142.749	FA	FA-02	3.17E-04	-8.05660878	117	127	Slug	1	Unpublished, ERM
GW-ON-114	114	S BMW	11564471.88	7019521.626	FA	FA-03	6.24E-04	-7.37936019	117	127	Slug	1	Unpublished, ERM
GW-ON-115	115	S BMW	11563306.57	7018223.853	On-site/Off-site Ground Water	Rivermont Acres; north of stream	1.52E-06	-13.3968002	127	137	Slug	1	Unpublished, ERM
GW-ON-116	116	S BMW	11564266.25	7020146.983	SB	VB-10	2.68E-07	-15.1322789	127	137	Slug	1	Unpublished, ERM
GW-ON-117	117	S BMW	11562876.36	7021214.757	WW	Emergency Basin	1.92E-04	-8.55801519	127	137	Slug	1	Unpublished, ERM
GW-ON-118	118	S BMW	11564897.52	7022154.409	VB	VB-05	1.02E-03	-6.88795265	137	147	Slug	1	Unpublished, ERM
GW-ON-119	119	S BMW	11564345.22	7022305.402	VB	VB-05	1.90E-05	-10.8710716	137	147	Slug	1	Unpublished, ERM
GW-ON-120	120	S BMW	11564039.34	7022311.436	VB	VB-04	6.33E-04	-7.36504014	137	147	Slug	1	Unpublished, ERM
GW-ON-201	201	I BMW	11566971.24	7022136.589	On-site	Background	4.29E-04	-7.75405364	147	157	Slug	1	Unpublished, ERM
GW-ON-202	202	I BMW	11566812.84	7019325.826	On-site/Off-site Ground Water	Southeastern portion of site	1.17E-02	-4.44816644	147	157	Slug	1	Unpublished, ERM
GW-ON-203	203	I BMW	11565235.36	7020210.268	FA	Fly Ash Pile	4.53E-04	-7.69961843	147	157	Slug	1	Unpublished, ERM
GW-ON-204	204	I BMW	11562893.84	7021592.037	WW	Treatment Plant	1.17E-03	-6.75075153	157	167	Slug	1	Unpublished, ERM
GW-ON-205	205	I BMW	11563687.69	7018994.959	SB	SB-02	7.10E-05	-9.55283068	157	167	Slug	1	Unpublished, ERM
GW-ON-207	207	I BMW	11565478.93	7020579.895	On-site/Off-site Ground Water	ZN RECOV	4.08E-04	-7.80424338	157	167	Slug	1	Unpublished, ERM
GW-ON-210	210	I BMW	11564691.74	7017477.817	SB	SB-05	4.53E-03	-5.39703334	167	177	Slug	1	Unpublished, ERM
GW-ON-215	215	I BMW	11563297.87	7018223	On-site/Off-site Ground Water	Rivermont Acres; north of stream	6.86E-07	-14.1923882	167	177	Slug	1	Unpublished, ERM
GW-ON-216	216	I BMW	11564259.16	7020143.011	SB	VB-10	3.96E-06	-12.4392665	167	177	Slug	1	Unpublished, ERM
GW-ON-301	301	D BMW	11566979.63	7022120.358	On-site	Background	4.14E-06	-12.3948148	96	109	Slug	1	Unpublished, ERM
GW-ON-302	302	D BMW	11566839.23	7019327.547	On-site/Off-site Ground Water	Southeastern portion of site	6.90E-08	-16.4891593	98	108	Slug	1	Unpublished, ERM
GW-ON-304	304	D BMW	11562895.47	7021576.301	WW	Treatment Plant	2.44E-06	-12.9235125	138	148	Slug	1	Unpublished, ERM
GW-ON-305	305	D BMW	11563860.51	7018978.444	SB	SB-02	7.53E-06	-11.7966155	75	85	Slug	1	Unpublished, ERM
GW-ON-316	316	D BMW	11564254.59	7020140.66	SB	VB-10	4.50E-04	-7.70626298	48	58	Slug	1	Unpublished, ERM

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Appendix C

Risk-Based Screening of Chemicals in Groundwater

AR302304

Table C-1. RBC screening of chemicals in groundwater at the Avtex site

Analyte	Number of Samples Analyzed	Samples above Detection Limit		Maximum Concentration Detected	U.S. EPA Region III RBC	Number of Exceedances [a]
		Number	Percent	(µg/L)	(µg/L)	
Inorganics						
Aluminum, total	193	186	96	51,700	3,700	28
Aluminum, dissolved	193	106	55	28,800	3,700	3
Antimony, total	193	28	15	1,750	1.5	28
Antimony, dissolved	193	38	20	911	1.5	38
Arsenic, total	193	152	79	7,960	0.045	152
Arsenic, dissolved	193	114	59	1,840	0.045	114
Barium, total	193	193	100	7,400	260	15
Barium, dissolved	193	192	99	5,400	260	7
Beryllium, total	193	57	30	5.5	7.3	--
Beryllium, dissolved	193	27	14	6.6	7.3	--
Cadmium, total	193	52	27	89.7	1.8	34
Cadmium, dissolved	193	12	6	9.2	1.8	9
Calcium, total	193	193	100	857,000	NA	NA
Calcium, dissolved	193	193	100	883,000	NA	NA
Chromium, total	193	97	50	1,400	11	55
Chromium, dissolved	193	58	30	340	11	32
Cobalt, total	193	106	55	1,000	220	20
Cobalt, dissolved	193	77	40	917	220	19
Copper, total	193	119	62	1,550	150	2
Copper, dissolved	193	65	34	175	150	1
Iron, total	193	193	100	4,920,000	1,100	181
Iron, dissolved	193	185	96	53,400	1,100	65
Lead, total	193	114	59	234	NA	NA
Lead, dissolved	193	61	32	65.1	NA	NA
Magnesium, total	193	193	100	236,000	NA	NA
Magnesium, dissolved	193	190	98	195,000	NA	NA
Manganese, total	193	192	99	26,700	510	100
Manganese, dissolved	193	182	94	25,800	510	82
Mercury, total	193	108	56	165	0.37 [b]	24
Mercury, dissolved	193	106	55	176	0.37 [b]	24
Nickel, total	193	142	74	1,920	73	33
Nickel, dissolved	193	109	56	1,870	73	28
Potassium, total	193	178	92	1,650,000	NA	NA
Potassium, dissolved	193	178	92	1,630,000	NA	NA
Selenium, total	193	70	36	48.5	18	5

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Table C-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit		Maximum Concentration Detected (µg/L)	U.S. EPA Region III RBC (µg/L)	Number of Exceedances [a]
		Number	Percent			
Inorganics (cont.)						
Selenium, dissolved	193	55	28	30.8	18	4
Silver, total	193	10	5	474	18	6
Silver, dissolved	193	10	5	1,570	18	3
Sodium, total	193	193	100	18,900,000	NA	NA
Sodium, dissolved	193	193	100	18,300,000	NA	NA
Thallium, total	193	33	17	20	0.26	33
Thallium, dissolved	193	14	7	24	0.26	14
Vanadium, total	193	79	41	1,010	26	28
Vanadium, dissolved	193	46	24	877	26	20
Zinc, total	193	129	67	11,400	1,100	11
Zinc, dissolved	193	170	88	9,590	1,100	8
Pesticides/PCBs						
Arochlor 1016	191	0	0	--	0.96	--
Arochlor 1221	191	0	0	--	0.033	--
Arochlor 1232	191	0	0	--	0.033	--
Arochlor 1242	191	0	0	--	0.033	--
Arochlor 1248	191	0	0	--	0.033	--
Arochlor 1254	191	0	0	--	0.033	--
Arochlor 1260	191	0	0	--	0.033	--
Aldrin	191	13	7	0.013	0.0039	7
α-Chlordane	191	32	17	1.6	0.19 [c]	2
γ-Chlordane	191	9	5	2.2	0.19 [c]	1
p,p'-DDD	191	11	6	0.52	0.28	1
p,p'-DDE	191	19	10	0.14	0.2	
p,p'-DDT	191	28	15	0.49	0.2	2
α-HCH	191	5	3	0.0076	0.011	
β-HCH	191	13	7	0.041	0.037	1
δ-HCH	191	1	1	0.0013	NA	NA
γ-HCH (lindane)	191	15	8	0.036	0.052	--
Dieldrin	191	20	10	3.5	0.0042	9
Endosulfan (i)	191	5	3	0.027	22	--
Endosulfan (ii)	191	4	2	0.082	22	--
Endosulfan sulfate	191	5	3	0.17	NA	NA
Endrin	191	27	14	0.62	1.1	--
Endrin aldehyde	191	4	2	0.06	NA	NA

AR302306

Table C-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit		Maximum Concentration Detected (µg/L)	U.S. EPA Region III RBC (µg/L)	Number of Exceedances [a]
		Number	Percent			
Pesticides/PCBs (cont.)						
Endrin ketone	191	6	3	0.16	NA	NA
Heptachlor	191	10	5	0.11	0.015	6
Heptachlor epoxide	191	1	1	0.012	0.0074	1
Methoxychlor	191	3	2	0.0091	18	--
Toxaphene	191	0	0	--	0.061	--
Semi-Volatile Organic Compounds						
Acenaphthene	193	0	0	--	37	--
Acenaphthylene	193	0	0	--	NA	NA
6-Amino hexanoic acid	2	2	100	6	NA	NA
Anthracene	193	0	0	--	180	--
1,2-Benzene carboxylic acid-diisooctyl ester	2	2	100	270	NA	NA
Benzeneacetic acid	4	4	100	530	NA	NA
Benzenediol isomer	1	1	100	57	NA	NA
Benzo(a)anthracene	193	0	0	--	0.092	--
Benzo(a)pyrene	193	0	0	--	0.0092	--
Benzo(b)fluoranthene	193	0	0	--	0.092	--
Benzo(g,h,i)perylene	193	0	0	--	NA	NA
Benzo(k)fluoranthene	193	0	0	--	0.92	--
Benzoic acid	24	24	100	1,000	15,000	--
Benzothiazole	2	2	100	7	NA	NA
2-(2h-Benzotriazol-2-yl)-4-methyl-phenol	2	2	100	940	NA	NA
2,6-Bis(1,1-dimethylethyl)1,4-benzenediol	1	1	100	4	NA	NA
Bis(2-chloroethoxy)methane	193	0	0	--	NA	NA
Bis(2-chloroethyl)ether	193	0	0	--	0.0096	--
Bis(2-ethylhexyl)phthalate	193	147	76	610	4.8	72
4-Bromophenyl phenyl ether	193	0	0	--	NA	NA
Butanoic acid	5	5	100	11,000	NA	NA
2-Butoxyethanol	1	1	100	28	NA	NA
2-(2-Butoxyethoxy)-ethanol	1	1	100	8	NA	NA
n-Butyl-benzenesulfonamide	4	4	100	40	NA	NA
Butylbenzylphthalate	193	1	1	6	730	--
Carbazole	193	0	0	--	3.3	--
Carboxylic acid isomers	1	1	100	6	NA	NA
Chlorinated propene isomer	1	1	100	6	NA	NA
4-Chloro-3-methyl-phenol	193	0	0	--	NA	NA

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Table C-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit		Maximum Concentration Detected (µg/L)	U.S. EPA Region III RBC (µg/L)	Number of Exceedances [a]
		Number	Percent			
***Semi-Volatile Organic* Compounds (cont.)**						
4-Chloroaniline	193	0	0	--	15	--
Chloroethanol phosphate	1	1	100	48	NA	NA
2-Chloronaphthalene	193	0	0	--	49	--
2-Chlorophenol	193	0	0	--	3	--
4-Chlorophenyl-phenylether	193	0	0	--	NA	NA
Chloropropene isomer	1	1	100	24	NA	NA
Chrysene	193	0	0	--	9.2	--
Cyclohexene-1-one isomer	3	3	100	4	NA	NA
Dibenz(a,h)anthracene	193	0	0	--	0.0092	--
Dibenzofuran	193	0	0	--	2.4	--
1,2-Dichlorobenzene	193	2	1	2	55	--
1,3-Dichlorobenzene	193	0	0	--	0.55	--
1,4-Dichlorobenzene	193	2	1	2	0.47	2
3,3'-Dichlorobenzidine	193	0	0	--	0.15	--
2,4-Dichlorophenol	193	0	0	--	11	--
Dichloropropene isomer	1	1	100	5	NA	NA
Diethyl phthalate	193	12	6	3	2,900	--
n,n-Dimethyl formamide	1	1	100	6	NA	NA
Dimethyl phthalate	193	2	1	3	37,000	--
2,4-Dimethyl-phenol	193	4	2	10	73	--
Di-n-butyl phthalate	193	1	1	1	370	--
4,6-Dinitro-2-methyl-phenol	193	0	0	--	0.37	--
2,4-Dinitrophenol	193	0	0	--	7.3	--
2,4-Dinitrotoluene	193	0	0	--	7.3	--
2,6-Dinitrotoluene	193	1	1	18	3.7	1
Di-n-octyl phthalate	193	0	0	--	73	--
Dodecanoic acid	1	1	100	10	NA	NA
Ethyl hexanoic acid	1	1	100	150	NA	NA
Ethyl pentenoat	1	1	100	48	NA	NA
2-Ethyl-hexanoic acid	2	2	100	640	NA	NA
Fluoranthene	193	0	0	--	150	--
Fluorene	193	0	0	--	24	--
Heptanone	1	1	100	81	NA	NA
Hexachlorobenzene	193	0	0	--	0.042	--
Hexachlorobutadiene	193	0	0	--	0.86	--

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Table C-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit		Maximum Concentration Detected (µg/L)	U.S. EPA Region III RBC (µg/L)	Number of Exceedances [a]
		Number	Percent			
Semi-Volatile Organic Compounds (cont.)						
Hexachlorocyclopentadiene	193	0	0	--	26	--
Hexachloroethane	193	0	0	--	4.8	--
Hexadecanoic acid	2	2	100	460	NA	NA
Hexamethylcyclotrisiloxane	2	2	100	2	NA	NA
Hexanoic acid	1	1	100	3	NA	NA
Hexathiepane	2	2	100	66	NA	NA
Hexen-1-ol	1	1	100	14	NA	NA
Hydroxy biphenyl isomer	2	2	100	17	NA	NA
4-Hydroxy-4-methyl-2-pentanone	1	1	100	62	NA	NA
8-Hydroxyoctanoic acid	2	2	100	16	NA	NA
Indeno(1,2,3-cd)pyrene	193	0	0	--	0.092	--
Isocrotonic acid	1	1	100	6	NA	NA
Isophorone	193	0	0	--	70	--
Methyl propanoic acid	1	1	100	4	NA	NA
3-Methyl-1h-indole	1	1	100	46	NA	NA
5-Methyl-2,4-diisopropylphenol	2	2	100	5	NA	NA
Methylated formamide	1	1	100	50	NA	NA
Methylated urea compound	3	3	100	3	NA	NA
2-Methyl-butanoic acid	1	1	100	35	NA	NA
3-Methyl-butanoic acid	1	1	100	1,800	NA	NA
4,4'-(1-Methylethylidene)bis-phenol	1	1	100	13	NA	NA
2-Methyl-naphthalene	193	3	2	1	NA	NA
Methylpentenediol isomer	1	1	100	5	NA	NA
2-Methyl-phenol	193	22	11	380	180	3
4-Methyl-phenol	193	42	22	1,600	18	18
2-Methyl-propanoic acid	1	1	100	1,500	NA	NA
Mono(2-ethylhexyl)ester-(9cl)-hexanedioic acid	1	1	100	240	NA	NA
Naphthalene	193	6	3	8	0.65	6
2-Nitroaniline	193	0	0	--	NA	NA
3-Nitroaniline	193	0	0	--	NA	NA
4-Nitroaniline	193	0	0	--	NA	NA
Nitrobenzene	193	1	1	96	0.35	1
2-Nitrophenol	193	0	0	--	NA	NA
4-Nitrophenol	193	1	1	19	29	--
n-Nitroso-di-n-propylamine	193	0	0	--	0.0096	--

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Table C-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit		Maximum Concentration Detected (µg/L)	U.S. EPA Region III RBC (µg/L)	Number of Exceedances [a]
		Number	Percent			
Semi-Volatile Organic Compounds (cont.)						
n-Nitrosodiphenylamine	193	0	0	--	14	--
Nonanedioic acid	1	1	100	110	NA	NA
Octanoic acid	1	1	100	270	NA	NA
Oxindol	1	1	100	130	NA	NA
2,2'-Oxybis(1-chloropropane)	193	0	0	--	NA	NA
Pentachlorophenol	193	2	1	20	0.56	2
Pentanoic acid	1	1	100	260	NA	NA
Phenanthrene	193	2	1	8	NA	NA
Phenol	193	52	27	21,000	2,200	15
Phenylene ethanone isomers	1	1	100	20	NA	NA
1,1'-(1,3-Phenylene)bis-ethanone	1	1	100	8	NA	NA
Pyrene	193	0	0	--	18	--
Sulfur (mol.)	18	18	100	4,100	NA	NA
Tetramethyl-urea	2	2	100	27	NA	NA
7-Thiabicyclo [4.1.0] heptane	1	1	100	5	NA	NA
Thiophenecarboxylic acid	1	1	100	79	NA	NA
2-Thiophenecarboxylic acid	3	3	100	150	NA	NA
1,2,4-Trichlorobenzene	193	0	0	--	19	--
2,4,5-Trichlorophenol	193	0	0	--	370	--
2,4,6-Trichlorophenol	193	0	0	--	6.1	--
1,2,3-Trimethyl-benzene	1	1	100	3	NA	NA
Volatile Organic Compounds						
Acetic acid	1	1	100	7	NA	NA
Acetone	276	77	28	3,400	61	17
Benzene	276	4	1	6	0.36	4
Bromodichloromethane	276	1	0	1	0.17	1
Bromoform	276	0	0	--	8.5	--
Bromomethane	276	1	0	3	0.85	1
2-Butanone	276	20	7	8,600	190	6
Carbon disulfide	276	140	51	1,700,000	100	53
Carbon tetrachloride	276	0	0	--	0.16	--
Chlorobenzene	276	0	0	--	11	--
Chloroethane	276	0	0	--	3.6	--
Chloroform	276	20	7	18	0.15	20
Chloromethane	276	0	0	--	2.1	--

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Table C-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit		Maximum Concentration Detected (µg/L)	U.S. EPA Region III RBC (µg/L)	Number of Exceedances [a]
		Number	Percent			
Volatile Organic Compounds (cont.)						
Cyanide	193	30	16	5,096	73	7
Cyclopentanol	1	1	100	18	NA	NA
Dibromochloromethane	276	0	0	--	0.13	--
1,1-Dichloroethane	276	0	0	--	80	--
1,2-Dichloroethane	552	0	0	--	0.12	--
1,1-Dichloroethylene	276	0	0	--	0.044	--
1,2-Dichloropropane	276	0	0	--	0.16	--
cis-1,3-Dichloropropene	276	0	0	--	0.077	--
trans-1,3-Dichloropropene	276	0	0	--	0.077	--
Ethylbenzene	276	4	1	2	130	--
Heptanal	1	1	100	5	NA	NA
2-Heptanone	2	2	100	23	NA	NA
Hexanal	2	2	100	200	NA	NA
2-Hexanone	276	5	2	26	150	--
Methanethiol	2	2	100	40	NA	NA
Methyl dioxolane	1	1	100	9	NA	NA
2-Methyl-1,3-dioxolane	3	3	100	7	NA	NA
4-Methyl-2-pentanone	276	2	1	2	NA	NA
Methylene chloride	276	38	14	4,300	4.1	21
3-Octanone	1	1	100	19	NA	NA
Oxybis-methane	1	1	100	210	NA	NA
Pentane	1	1	100	9	NA	NA
2-Propanol	1	1	100	5	NA	NA
Styrene	276	0	0	--	160	--
Sulfur dioxide	5	5	100	1,500	NA	NA
1,1,2,2-Tetrachloroethane	276	0	0	--	0.053	--
Tetrachloroethylene	276	0	0	--	1.1	--
Thiobis-methane	1	1	100	5	NA	NA
Toluene	276	37	13	46	75	--
1,1,2-Trichloro-1,2,2-trifluoroethane	1	1	100	5	5,900	--
1,1,1-Trichloroethane	276	0	0	--	320	--
1,1,2-Trichloroethane	276	0	0	--	0.19	--
Trichloroethene	276	1	0	2	1.6	1
Vinyl chloride	276	1	0	1	0.019	1
Xylenes, total	276	7	3	1,800	1,200	1

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Table C-1. (cont.)

Analyte	Number of Samples Analyzed	Samples above Detection Limit		Maximum Concentration Detected (µg/L)	U.S. EPA Region III RBC (µg/L)	Number of Exceedances [a]
		Number	Percent			
Miscellaneous						
Ammonia nitrogen	54	33	61	22,000	21	33
Carbonate (as $CaCO_3$)	54	11	20	21,300,000	NA	NA
Chloride	19	18	95	85,500	NA	NA
Chloride (titrimetric)	34	34	100	12,000,000	NA	NA
Hydroxide	17	0	0	--	NA	NA
Nitrate nitrogen	37	9	24	40,000	NA	NA
Nitrate/nitrite	17	16	94	15,100	NA	NA
Nitrite nitrogen	37	4	11	80	370 [d]	--
Sulfate	17	17	100	3,640,000	NA	NA
Sulfate (turbidimetric)	37	37	100	6,000,000	NA	NA
Sulfide	54	10	19	680,000	NA	NA
Total dissolved solids	54	54	100	52,500,000	NA	NA

Note -- - no exceedances
NA - not applicable

[a] Excludes data below detection limits.

[b] Criteria listed is the value for Methyl-mercury.

[c] Criteria listed is the value for Chlordane.

[d] Criteria listed is the value for Nitrite.

AR302312

Table C-2. Concentration-toxicity screen for chemicals in groundwater at the Avtex site

Analyte	Maximum Conc. in Groundwater (µg/L)	Non-Carcinogen Toxicity Value 1/RfD	Chemical-Specific Risk Factor Rij	Relative Risk Factors for Non-Carcinogens Rij/Rj	Carcinogenic Toxicity Value CSF	Chemical-Specific Risk Factor Rij_c	Relative Risk Factor for Carcinogens Rij_c/Rj_c
Inorganics							
Aluminum	51,700	1.0	51,700	0.00071	--	--	--
Ammonia nitrogen	22,000	35	769,231	**0.0106**	--	--	--
Antimony	1,750	2,500	4,375,000	**0.0603**	--	--	--
Arsenic	7,960	3,333	26,533,333	**0.3656**	15.1	120196	**0.674**
Barium	7,400	14	105,714	0.0015	--	--	--
Beryllium	5.5	500	2,750	0.000038	8.4	46.2	0.00026
Cadmium	89.7	17,544	1,573,684	**0.0217**	6.3	565.11	0.00317
Calcium[a]	857,000	--	--	--	--	--	--
Chromium	1,400	333	466,667	**0.0064**	41	57400	**0.322**
Cobalt	1,000	--	--	--	--	--	--
Copper	1,550	25	38,750	0.0005	--	--	--
Cyanide	5,096	50	254,800	0.0035	--	--	--
Iron	4,920,000	3.3	16,400,000	**0.2260**	--	--	--
Lead[a]	234	--	--	--	--	--	--
Magnesium[a]	236,000	--	--	--	--	--	--
Manganese	26,700	50	1,335,000	**0.0184**	--	--	--
Mercury	165	11,628	1,918,605	**0.0264**	--	--	--
Nickel	1,920	50	96,000	0.0013	--	--	--
Potassium[a]	1,650,000	--	--	--	--	--	--
Selenium	48.5	200	9,700	0.0001	--	--	--
Silver	474	200	94,800	0.0013	--	--	--
Sodium[a]	18,900,000	--	--	--	--	--	--
Thallium	20	14286	285,714	0.0039	--	--	--
Vanadium	1,010	143	144,286	0.0020	--	--	--
Zinc	11,400	3.3	38,000	0.0005	--	--	--
Pesticides/PCBs							
Aldrin	0.013	33,333	433	0.000006	17	0.221	0.0000012
α–HCH	0.0076	--	--	--	6.3	0.04788	0.0000003
β–HCH	0.041	--	--	--	1.8	0.0738	0.0000004
δ–HCH[a]	0.0013	--	--	--	--	--	--
γ–HCH (lindane)	0.036	3,333	120	0.000002	1.3	0.0468	0.0000003
α-Chlordane	1.6	5,000	8,000	0.00011	0.35	0.56	0.0000031
γ-Chlordane	2.2	5,000	11,000	0.00015	0.35	0.77	0.0000043
p,p'-DDD	0.52	--	--	--	0.24	0.1248	0.0000007
p,p'-DDE	0.14	--	--	--	0.34	0.0476	0.0000003

AR302313

Table C-2. (cont.)

Analyte	Maximum Conc. in Groundwater (µg/L)	Non-Carcinogen Toxicity Value 1/RfD	Chemical-Specific Risk Factor Rij	Relative Risk Factors for Non-Carcinogens Rij/Rj	Carcinogenic Toxicity Value CSF	Chemical-Specific Risk Factor Rij_c	Relative Risk Factor for Carcinogens Rij_c/Rj_c
Pesticides/PCBs (cont.)							
p,p'-DDT	0.49	2,000	980	0.00001	0.34	0.1666	0.0000009
Dieldrin	3.5	20,000	70,000	0.00096	16	56	0.00031
Endosulfan (i)	0.027	167	5	0.00000006	--	--	--
Endosulfan (ii)	0.082	167	14	0.00000019	--	--	--
Endosulfan sulfate[a]	0.17	--	--	--	--	--	--
Endrin	0.62	3,333	2,067	0.00003	--	--	--
Endrin aldehyde[a]	0.06	--	--	--	--	--	--
Endrin ketone[a]	0.16	--	--	--	--	--	--
Heptachlor	0.11	2,000	220	0.000003	4.5	0.495	0.0000028
Heptachlor Epoxide	0.012	76,923	923	0.000013	9.1	0.1092	0.0000006
Methoxychlor	0.0091	200	2	0.00000003	--	--	--
Semi-Volatile Organic Compounds							
6-Amino hexanoic acid[a]	6	--	--	--	--	--	--
1,2-Benzene carboxylic acid-diisooctyl ester[a]	270	--	--	--	--	--	--
Benzeneacetic acid[a]	530	--	--	--	--	--	--
Benzenediol isomer[a]	57	--	--	--	--	--	--
Benzoic acid	1,000	0.25	250	0.0000034	--	--	--
Benzothiazole[a]	7	--	--	--	--	--	--
2-(2h-Benzotriazol-2-yl)-4-methyl-phenol[a]	940	--	--	--	--	--	--
2,6-bis(1,1-Dimethylethyl)1,4-benzenediol[a]	4	--	--	--	--	--	--
bis(2-Ethylhexyl)phthalate	610	50	30,500	0.000420	0.014	8.54	0.0000479
Butanoic acid[a]	11,000	--	--	--	--	--	--
2-Butoxyethanol[a]	28	--	--	--	--	--	--
2-(2-Butoxyethoxy)-ethanol[a]	8	--	--	--	--	--	--
n-Butyl-benzenesulfonamide[a]	40	--	--	--	--	--	--
Butylbenzylphthalate	6	5	30	0.0000004	--	--	--
Carboxylic acid isomers[a]	6	--	--	--	--	--	--
Chlorinated propene isomer[a]	6	--	--	--	--	--	--
Chloroethanol phosphate[a]	48	--	--	--	--	--	--
Chloropropene isomer[a]	24	--	--	--	--	--	--
Cyclohexene-1-one isomer[a]	4	--	--	--	--	--	--
1,2-Dichlorobenzene	2	11	22	0.0000003	--	--	--
1,4-Dichlorobenzene	2	33	67	0.000001	0.024	0.048	0.0000003
Dichloropropene isomer[a]	5	--	--	--	--	--	--
Diethyl phthalate	3	1.25	4	0.0000001	--	--	--

AR302314

Table C-2. (cont.)

Analyte	Maximum Conc. in Groundwater (µg/L)	Non-Carcinogen Toxicity Value 1/RfD	Chemical-Specific Risk Factor Rij	Relative Risk Factors for Non-Carcinogens Rij/Rj	Carcinogenic Toxicity Value CSF	Chemical-Specific Risk Factor Rij_c	Relative Risk Factor for Carcinogens Rij_c/Rj_c
Semi-Volatile Organic Compounds (cont.)							
n,n-Dimethyl formamide[a]	6	--	--	--	--	--	--
Dimethyl phthalate	3	0.10	0	0.000000004	--	--	--
2,4-Dimethyl-phenol	10	50	500	0.0000069	--	--	--
Di-n-butyl phthalate[a]	1	--	--	--	--	--	--
2,6-Dinitrotoluene	18	1,000	18,000	0.00025	--	--	--
Dodecanoic acid[a]	10	--	--	--	--	--	--
mono(2-Ethylhexyl)ester-(9cl)-hexanedioic acid[a]	240	--	--	--	--	--	--
Ethyl hexanoic acid[a]	150	--	--	--	--	--	--
Ethyl pentenoat[a]	48	--	--	--	--	--	--
2-Ethyl-hexanoic acid[a]	640	--	--	--	--	--	--
Heptanone[a]	81	--	--	--	--	--	--
Hexadecanoic acid[a]	460	--	--	--	--	--	--
Hexamethylcyclotrisiloxane[a]	2	--	--	--	--	--	--
Hexanoic acid[a]	3	--	--	--	--	--	--
Hexathiepane[a]	66	--	--	--	--	--	--
Hexen-1-ol[a]	14	--	--	--	--	--	--
Hydroxy biphenyl isomer[a]	17	--	--	--	--	--	--
4-Hydroxy-4-methyl-2-pentanone[a]	62	--	--	--	--	--	--
8-Hydroxyoctanoic acid[a]	16	--	--	--	--	--	--
Isocrotonic acid[a]	6	--	--	--	--	--	--
Methyl propanoic acid[a]	4	--	--	--	--	--	--
3-Methyl-1h-indole[a]	46	--	--	--	--	--	--
5-Methyl-2,4-diisopropylphenol[a]	5	--	--	--	--	--	--
Methylated formamide[a]	50	--	--	--	--	--	--
Methylated urea compound[a]	3	--	--	--	--	--	--
2-Methyl-butanoic acid[a]	35	--	--	--	--	--	--
3-Methyl-butanoic acid[a]	1,800	--	--	--	--	--	--
4,4'-(1-Methylethylidene)bis-phenol[a]	13	--	--	--	--	--	--
2-Methyl-naphthalene[a]	1	--	--	--	--	--	--
Methylpentenediol isomer[a]	5	--	--	--	--	--	--
2-Methyl-phenol	380	20	7,600	0.00010	--	--	--
4-Methylphenol	1,600	200	320,000	0.004409	--	--	--
2-Methyl-propanoic acid[a]	1,500	--	--	--	--	--	--
Naphthalene	8	1,111	8,889	0.000122	--	--	--
Nitrobenzene	96	2,000	192,000	0.002645	--	--	--

AR302315

Table C-2. (cont.)

Analyte	Maximum Conc. in Groundwater (µg/L)	Non-Carcinogen Toxicity Value 1/RfD	Chemical-Specific Risk Factor Rij	Relative Risk Factors for Non-Carcinogens Rij/Rj	Carcinogenic Toxicity Value CSF	Chemical-Specific Risk Factor Ri_c	Relative Risk Factor for Carcinogens Rij_c/Ri_c
Semi-Volatile Organic Compounds (cont.)							
4-Nitrophenol	19	125	2,375	0.000033	--	--	--
Nonanedioic acid[a]	110	--	--	--	--	--	--
Octanoic acid[a]	270	--	--	--	--	--	--
Oxindol[a]	130	--	--	--	--	--	--
Pentachlorophenol	20	33	667	0.000009	0.12	2.4	0.0000135
Pentanoic acid[a]	260	--	--	--	--	--	--
Phenanthrene[a]	8	--	--	--	--	--	--
Phenol	21,000	1.67	35,000	0.000482	--	--	--
Phenylene ethanone isomers[a]	20	--	--	--	--	--	--
1,1'-(1,3-Phenylene)bis-ethanone[a]	8	--	--	--	--	--	--
Tetramethyl-urea[a]	27	--	--	--	--	--	--
7-Thiabicyclo [4.1.0] heptane[a]	5	--	--	--	--	--	--
Thiophenecarboxylic acid[a]	79	--	--	--	--	--	--
2-Thiophenecarboxylic acid[a]	150	--	--	--	--	--	--
Trimethylbenzene isomer[a]	39	--	--	--	--	--	--
1,2,3-Trimethyl-benzene[a]	3	--	--	--	--	--	--
Volatile Organic Compounds							
Acetic acid[a]	7	--	--	--	--	--	--
Acetone	3,400	10	34,000	0.00047	--	--	--
Benzene	6	588	3,529	0.000049	0.029	0.174	0.0000010
Bromodichloromethane	1	50	50	0.0000007	0.062	0.062	0.0000003
Bromomethane	3	714	2,143	0.000030	--	--	--
2-Butanone	8,600	3.5	30,070	0.00041	--	--	--
Carbon disulfide	1,700,000	10	17,000,000	**0.2342**	--	--	--
Chloroform	18	11,628	209,302	0.00288	0.081	1.458	0.0000082
Cyclopentanol[a]	18	--	--	--	--	--	--
Ethylbenzene	2	10	20	0.0000003	--	--	--
Heptanal[a]	5	--	--	--	--	--	--
2-Heptanone[a]	23	--	--	--	--	--	--
Hexanal[a]	200	--	--	--	--	--	--
2-Hexanone	26	25	650	0.000009	--	--	--
Methanethiol[a]	40	--	--	--	--	--	--
Methyl dioxolane[a]	9	--	--	--	--	--	--
Methylene chloride	4,300	17	71,667	0.00099	0.0075	32.25	0.0001809
2-Methyl-1,3-dioxolane[a]	7	--	--	--	--	--	--

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Table C-2. (cont.)

Analyte	Maximum Conc. in Groundwater (µg/L)	Non-Carcinogen Toxicity Value 1/RfD	Chemical-Specific Risk Factor Rij	Relative Risk Factors for Non-Carcinogens Rij/Rj	Carcinogenic Toxicity Value CSF	Chemical-Specific Risk Factor Rij_c	Relative Risk Factor for Carcinogens Rij_c/Rj_c
Volatile Organic Compounds (cont.)							
4-Methyl-2-pentanone[a]	2	--	--	--	--	--	--
3-Octanone[a]	19	--	--	--	--	--	--
Oxybis-methane[a]	210	--	--	--	--	--	--
Pentane[a]	9	--	--	--	--	--	--
2-Propanol[a]	5	--	--	--	--	--	--
Sulfur dioxide[a]	1,500	--	--	--	--	--	--
Thiobis-methane[a]	5	--	--	--	--	--	--
Toluene	46	5	230	0.0000032	--	--	--
Trichloroethene	2	167	333	0.000005	0.011	0.022	0.0000001
1,1,2-Trichloro-1,2,2-trifluoroethane	5	0.033	0.17	0.000000002	--	--	--
Vinyl chloride	1	--	--	--	1.9	1.9	0.0000107
Xylenes (Total)	1,800	0.5	900	0.0000124	--	--	--
Miscellaneous							
Chloride[a]	85,500	--	--	--	--	--	--
Nitrate nitrogen	40,000	0.625	25,000	0.00034	--	--	--
Nitrate/nitrite[a]	15,100	--	--	--	--	--	--
Nitrite nitrogen	80	10	800	0.00001	--	--	--
Sulfate[a]	3,640,000	--	--	--	--	--	--
Sulfide[a]	680,000	--	--	--	--	--	--

Note: Chemicals contributing more then 1 percent of total risk (either as carcinogens or non-carcinogens) are highlighted.
Both oral and inhalation toxicity values were considered, if available, and the values yielding the most conservative relative risk factors were used.

-- - not applicable
1/RfD - 1/chemical specific reference dose
Rij - risk factor for chemical *i* in medium *j* (noncarcinogenic)
Rj - total risk factor for medium *j* (noncarcinogenic) = 72,582,095
Rij/Rj - ratio of the risk factor for each chemical to the total risk factor; approximates the relative risk for each chemical in medium *j (noncarcinogenic)*
CSF - cancer slope factor
Rij_c - risk factor for chemical *i* in medium *j* (carcinogenic)
Rj_c - total risk factor for medium *j* (carcinogenic) = 178,313
Rij_c/Rj_c - ratio of the risk factor for each chemical to the total risk factor; approximates the relative risk for each chemical in medium *j (carcinogenic)*

[a] No toxicity data available in the EPA Region III RBC table.

AR302317

Appendix D

Bench-Scale Feasibility Testing of Electrical Resistance Heating for Remediation of Waste Viscose

AR302318

Scope of Work:
Feasibility Testing for Electrical Resistance Heating

Exponent will obtain representative, relatively undisturbed, 1- or 2-inch-diameter, waste material core samples. Samples will be 12 inches long, sealed and capped in moisture-proof liners.

Samples will be collected from three depths at a representative location in each viscose basin. Target depths are 4 ft (middle of unsaturated zone, high CS_2 level), 8 ft (bottom of unsaturated zone, possible capillary fringe zone, high CS_2 level), and 16 ft (saturated zone, high CS_2 level). Actual sample depths will be field determined by Exponent depending on site conditions.

Exponent will obtain three representative grab samples of water, one from each sample location, collected from below the water table. Samples will be collected in 1-L plastic containers with no preservatives.

Exponent will measure the actual undisturbed shallow groundwater temperature (or determine the annual average air temperature at site ground level).

Exponent will ship the nine waste and three water samples to AHA's Calgary lab.

AHA will test nine waste samples for static electrical conductivity (EC) at lab temperature, and one for dynamic electrical conductivity, to determine EC as a function of temperature.

AHA will test three water samples for static electrical conductivity at room temperature, 40 °C, and 80 °C.

AHA will test two of the waste samples for static thermal conductivity at room temperature.

If air and/or water permeability, bulk density, and porosity have already been characterized for the site, Exponent will provide those data. If these parameters have not been determined, Exponent will obtain six additional waste material core samples from similar depths, to be tested for these parameters by Exponent.

AHA will perform preliminary modeling of the test area to determine vapor removal potential, power requirements, appropriate well and electrode spacing, and approximate time for test-area cleanup. This effort will provide an initial evaluation as to whether this technology is technically feasible and cost effective, and will provide data for system design.

Exponent will provide site characterization data, including:

- Map(s), preferably in AutoCAD R14, showing the areas to be remediated and the power line(s) adjacent to that area.
- Elevation contours for base of waste, top of waste, and water table.
- Existing groundwater remediation system (if any).
- Nature and hydraulic conductivity of material underlying waste.

Exponent will locate the desired pilot test area and indicate its approximate size (e.g., 30×60 ft).

Exponent will determine the desired remediation time for the entire project (e.g., 3 years).

Exponent will determine the locations of buried underground electric cables, telecom lines, or metal conductors (e.g., gas or water pipes) in the areas to be remediated, if any.

Exponent will determine the available power supply parameters as follows:

- Name of power company, and name and telephone number of contact person
- Distance from power line to test area
- Power line voltage and available amperage
- Service configuration (delta, Y, etc.)
- An example of a current commercial power contract, if available.

Exponent will provide costs for preparing drilling access, drilling 10-inch borings to the base of the waste for electrode installation, and a rig hourly rate, including crew, for electrode installation. Electrodes are approximately 25 ft long and weigh 200 lb.

Exponent will indicate the availability of clean water supply for electrode cooling (approx. 4 gpm for the test area), and options for disposal of cooling water (approx. 200 °F) and dewatering product (probably high CS_2). If no onsite water treatment facilities are available for the pilot test, AHA will add this element to the cost estimate.

AHA will contact the power company to determine the cost of providing power to the test area.

AHA will prepare a cost estimate for performing a pilot test in the test area. This estimate will include a breakdown of capital equipment (including power supply, controller, electrodes, electrode cooling system, matrix dewatering, aqueous-phase treatment, vacuum system, and vapor-phase treatment), installation, and pilot operations/reporting.

AHA will also prepare a preliminary cost estimate for remediating the entire area in the desired time. The estimate will be presented in dollars per calendar year ($/c.y.). This estimate will be subject to modification in light of pilot test results, ongoing characterization, and ongoing operational experience.